# NAVAL POSTGRADUATE SCHOOL

## Monterey, California

# THESIS

BENEFIT/COST ANALYSIS OF INTERDWELLING NOISE CONTROL IN MULTIFAMILY DWELLINGS

by

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and
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December, 1991

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

# REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION<br>Unclassified | 1b. RESTRICTIVE MARKINGS |
| 2a. SECURITY CLASSIFICATION AUTHORITY | 3. DISTRIBUTION/AVAILABILITY OF REPORT<br>Approved for public release; distribution is unlimited. |
| 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE | |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S) | 5. MONITORING ORGANIZATION REPORT NUMBER(S) |
| 6a. NAME OF PERFORMING ORGANIZATION<br>Naval Postgraduate School<br>6b. OFFICE SYMBOL (*If applicable*)<br>AS | 7a. NAME OF MONITORING ORGANIZATION<br>Naval Postgraduate School |
| 6c. ADDRESS (*City, State, and ZIP Code*)<br>Monterey, CA 93943-5000 | 7b. ADDRESS (*City, State, and ZIP Code*)<br>Monterey, CA 93943-5000 |
| 8a. NAME OF FUNDING/SPONSORING ORGANIZATION<br>8b. OFFICE SYMBOL (*If applicable*) | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER |
| 8c. ADDRESS (*City, State, and ZIP Code*) | 10. SOURCE OF FUNDING NUMBERS<br>Program Element No · Project No · Task No · Work Unit Accession Number |

11. TITLE (*Include Security Classification*)
Benefit/Cost Analysis of Interdwelling Noise Control in Multifamily Dwellings (Unclassified)

12. PERSONAL AUTHOR(S) Augustine, Paul K. and Rowlands, W. Drew

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (*year, month, day*) | 15. PAGE COUNT |
|---|---|---|---|
| Master's Thesis | From To | December, 1991 | 111 |

16. SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

| 17. COSATI CODES | | | 18. SUBJECT TERMS (*continue on reverse if necessary and identify by block number*) |
|---|---|---|---|
| FIELD | GROUP | SUBGROUP | Net present value, Interdwelling noise, sound transmission, willingness to pay, building code. |

19. ABSTRACT (*continue on reverse if necessary and identify by block number*)


This thesis was undertaken to perform a benefit/cost analysis of interdwelling noise control in multifamily dwellings. Specifically, the benefit/cost analysis was performed to determine whether multifamily dwelling owners would find it economically beneficial to provide multifamily dwellings that are insulated from interdwelling noise. In other words, does the marginal benefit to the owner (additional monthly rent) exceed the marginal cost of providing the added insulation?

A questionnaire was used to survey tenants of one multifamily apartment complex in Monterey, CA to show that a market does indeed exist for sound insulated multifamily dwellings. (ie: tenants are willing to pay to attenuate interdwelling noise), and that the amount they are willing to pay is relatively large compared to the marginal cost of providing the added interdwelling sound insulation (ie: the amount that tenatns have to pay for additional sound insulation to make the benefit/cost ratio greater than one is relatively small). The survey also ascertained attitudes towards noises where quiet surroundings are important to tenants in deciding where to rent, noise is annoying to the m to a relatively large degree, and that interdwelling noise is more annoying than outdoor noises.


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|---|---|
| 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT<br>☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS REPORT ☐ DTIC USERS | 21. ABSTRACT SECURITY CLASSIFICATION<br>Unclassified |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL<br>Paul M. Carrick | 22b. TELEPHONE (*Include Area code*)<br>(408) 646-2939 · 22c. OFFICE SYMBOL<br>Code 54ca |

**DD FORM 1473, 84 MAR** 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

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# BENEFIT/COST ANALYSIS OF INTERDWELLING NOISE CONTROL IN MULTIFAMILY DWELLINGS

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
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# ABSTRACT

This thesis was undertaken to perform a benefit/cost analysis of interdwelling noise control in multifamily dwellings. Specifically, the benefit/cost analysis was performed to determine whether multifamily dwelling owners would find it economically beneficial to provide multifamily dwellings that are insulated from interdwelling noise. In other words, does the marginal benefit to the owner (additional monthly rent) exceed the marginal cost of providing the added insulation?

A questionnaire was used to survey tenants of one multifamily apartment complex in Monterey, CA to show that a market does indeed exist for sound insulated multifamily dwellings (ie: tenants are willing to pay to attenuate interdwelling noise), and that the amount they are willing to pay is relatively large compared to the marginal cost of providing the added interdwelling sound insulation (ie: the amount that tenants have to pay for additional sound insulation to make the benefit/cost ratio greater than one is relatively small). The survey also ascertained attitudes towards noise where quiet surroundings are important to tenants in deciding where to rent, where noise is annoying to them to a relatively large degree, and where interdwelling noise is more annoying than outdoor noises.

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# I. INTRODUCTION

## A. GENERAL

Many articles and books have been written on the "supply side" of noise abatement technology in the architectural and construction industries where the materials and knowledge exist to construct acoustically controlled buildings. This thesis will attempt to quantify in monetary terms the "demand side" for noise abatement in multifamily dwellings. An attempt will be made to prove that it is possible to indicate the value tenants place upon the environmental intangible commodity "peace and quiet" by showing that a market exists for sound abatement in multifamily dwellings. This will be done by showing that the marginal benefit to the tenant (i.e. what he or she is willing to pay for additional sound insulation) exceeds the marginal cost to the builder of providing the additional sound insulation.

## B. BACKGROUND

### 1. Outdoor Noise

Although noise has become accepted as an environmental hazard, most of the state and national government studies about its economic effects on society have concentrated on noise in communities surrounding airports. Because of the concern about the effects of noise on people, other community

surveys have concentrated on **outdoor** measurements of noise in residential areas with few measurements taken elsewhere. [Ref. 1] However, many communities do not actively perform noise surveys, but rely on complaints from citizens to measure the effect of noise levels on the community.

> ...information on the community response [to noise] is gleaned from comments on the number of telephoned complaints and the number of letters of complaint,...A carefully planned and executed opinion survey of communities exposed to noise would give much more precise data on the response [to noise]. Such surveys are rarely made, however. [Ref. 2]

According to Starkie and Johnson, the frontier of acoustics as it pertains to human environments is in the *measurement* of annoyance levels in real life situations, and it is here that research is most lacking and agreement hard to achieve.

The difficulty in reaching agreement in measuring annoyance levels is due to the subjective nature of noise in the human environment. Noise is commonly defined as "unwanted" sound. All noise is acoustic energy and its effects are subjective because it is a function of an individual's perceptions and attitudes. As a result of certain physical characteristics, a noise problem may deteriorate as a result of changes in personal values. [Ref. 3] A noise that was once annoying may become, through repetition alone, to be acceptable over time and vice versa.

### 2. Interdwelling Noise

Although the relatively few surveys conducted to ascertain the levels of annoyance to outdoor sources of noise have been mostly confined to airport noise, even fewer surveys have been performed to fully grasp the effect of noise on people from indoor environments, especially in multifamily dwellings.

> ...Indoor noise environments often are inferred from such outdoor measurements, but this procedure may result in sizable errors through neglect of the noise generated by indoors activities or the lack of accurate information about the noise reduction provided by the building structure. [Ref. 4]

Noises from a variety of sources both internal and external to a building structure may annoy tenants of the dwelling; however, this thesis is primarily concerned with the noise that is internal to the structure. This type of noise, referred to as interdwelling noise, is a result of the dwelling units of the complex sharing common structural elements, such as common walls and/or common floor/ceiling assemblies.

## C. OBJECTIVES

The central question our thesis will attempt to answer is: Does the average amount that tenants are willing to pay for additional sound attenuation, a measure of their perceived benefit, outweigh the marginal cost of providing the additional insulation? The marginal cost of providing the

added sound insulation is based upon the difference between the original sound insulation built into the structure (which is discussed in Chapter III) and a level of sound insulation that would eliminate nearly all interdwelling noise (a level of sound insulation above what current building codes require). The current monthly rent paid by tenants is used as the base from which the incremental amount that they are willing to pay is measured.

Through the use of a survey (see Appendix A), our thesis will attempt to demonstrate that a market exists for interdwelling sound insulation by answering the following questions:

1. To what degree does noise annoy tenants?
2. Is this annoyance level sufficient to make tenants willing to pay an additional amount in monthly rent to abate the noise? (ie: Does a market exist for the good "peace and quiet"?)
3. How much are tenants willing to pay for additional sound insulation in their building? In essence, what is the value to them of the commodity "peace and quiet"?

Further, by utilizing construction cost manuals, our thesis will try to answer the following question:

What is the marginal cost of providing sufficient sound insulation to nearly eliminate interdwelling noise?

## D. SCOPE, LIMITATIONS & ASSUMPTIONS

### 1. Scope

The scope of this thesis will focus on residents of one private multifamily dwelling complex, the Monterey Pines Apartments complex, in the city of Monterey, CA. In addition to ascertaining the reactions and attitudes of the tenants of this complex toward noise and their willingness to pay for additional sound insulation in their building's structure, sound transmission standards used in the design and construction of the building will be studied.

The following are beyond the scope of this thesis:

- Public housing projects, private housing complexes appealing to low income individuals (current building codes require contractors to comply with minimum standards for sound insulation in all multifamily dwellings regardless of the incomes of the tenants) and military housing will not be covered.
- Interaction between architects and construction companies in determining the sound insulation that will be built into a particular structure as well as the types of materials available in the marketplace to provide sound insulation will not be covered.
- Exterior sound transmission control will not be addressed.
- Noise control in military family housing will specifically not be discussed since they are subject to different building codes and standards.
- Discussion of the social and psychological effects of noise on humans will not be covered.

### 2. Limitations

The Monterey Pines Apartment complex consists of 286 units of which thirty were randomly selected to participate in

the survey (see Appendix B). The surveys were mailed to the tenants of these units with a resulting fifty percent response rate. The conclusions and recommendations of this thesis are drawn based on this sample, which is restricted by those who responded. Therefore, this sample is not a statistical representation of the population of 286 units, and may not be indicative of this population as a whole nor of the population of all tenants who reside in similar or other types of multifamily dwellings in the United States.

### 3. Assumptions

In developing this thesis, a number of assumptions were made:

- Noise is a disbenefit to tenants of multifamily dwellings.
- An implicit market exists for environmental attributes (ie: "peace and quiet").
- That, although people differ in their tastes and the emphasis they place on environmental attributes, the majority of them would like to be rid of sources of noise that are not under their control.[Ref. 5]
- The STC and IIC ratings (see definitions and abbreviations) for the original construction of the Monterey Pines Apartments (which was completed prior to the existence of any sound insulation requirements) approximately equate to current building code requirements for sound insulation. The assumption is, therefore, that the additional level of sound insulation that tenants desire would exceed current building codes if provided.

## E. LITERATURE REVIEW AND METHODOLOGY

### 1. Literature Review

Research covered analysis of the Uniform Building Code, the California State Building Code, and Monterey city codes. A review of the plans and specifications for construction of the Monterey Pines Apartments complex, on file in the building department of the city of Monterey, were used to determine the sound insulation considerations used in designing and constructing the complex.

Phone interviews concerning previous studies of noise control in multifamily dwellings were conducted with the California Department of Health Services, Office of Noise Control. Additionally, other federal government documents, such as noise control guides provided by the Environmental Protection Agency, the Federal Housing Administration, and the Office of Housing and Urban Development, were obtained and analyzed through contact with the Office of Noise Control. Information was also obtained through various pertinent books and other publications.

### 2. Methodology

A questionnaire (see Appendix A) was developed to measure tenants' attitudes towards various sounds as well as to determine their willingness to pay for increased noise insulation within the building structure.

A method of providing added sound insulation within the apartments as well as for determining the marginal cost to perform the additional construction was developed utilizing construction cost estimating manuals.

## F. DEFINITIONS AND ABBREVIATIONS

*Sound Transmission Class (STC)* - A single number rating used to compare walls, floor/ceiling assemblies and doors for their sound insulating properties with respect to speech and small household appliance noise.[Ref. 6] The STC is derived in a laboratory setting where sound from a source room is transmitted to a receiving room only through the wall or floor being tested. The difference in sound levels over sixteen different frequency bands are measured over time. These differences are evaluated and yield a single number rating. [Ref. 7]

*Impact Insulation Class (IIC)* - A single number rating used to compare the effectiveness of floor/ceiling assemblies in providing reduction of impact generated sounds, such as footsteps. The IIC is derived from laboratory measurements of the pressure level of impact sounds across a series of 16 test bands using a standardized tapping machine. [Ref. 8]

*Uniform Building Code (UBC)* - A legal document which sets forth requirements to protect the public's health, safety, and general welfare as they relate to the construction and

occupancy of buildings structures. The UBC does this by establishing minimum standards that regulate and control the design, construction, quality of materials, use and occupancy, location, and maintenance of all buildings and structures within a jurisdiction. [Ref. 9]

## G. ORGANIZATION OF STUDY

Chapter II will provide an historical background and the current trends relating to the noise control problem in multifamily dwellings. Chapter III discusses the types of sound encountered in these building structures. Methods for the measurement of sound transmission within the dwellings are also discussed in this chapter as well as the applicable building codes. Finally, the level of sound insulation in Monterey Pines Apartments will be quantified with an STC and an IIC rating.

Chapter IV presents an analysis of the questionnaire design and the conclusions drawn from the responses received. A benefit/cost analysis is performed in Chapter V to compare a mean value for what tenants are willing to pay against the marginal cost to the builder of providing additional sound insulation. Chapter VI provides a summary of the conclusions and recommendations for further areas of research.

## II. THE INTERDWELLING NOISE PROBLEM

### A. HISTORICAL PERSPECTIVE

Before the turn of the century, large multifamily buildings were constructed with masonry walls, up to eight feet in thickness, which prevented much of the sound transmission between rooms in the buildings. During the 1950's and 1960's, solid, load bearing, masonry walls became too expensive and were replaced by lighter more flexible steel frames. Interior walls were constructed with wood framing using 2" x 4" studs typically placed 16 inches apart. They were then plastered or "dry-walled" to enclose the frame on both sides. This created, in effect, a drum where sounds were easily transmitted. [Ref. 10]

### B. THE CURRENT NOISE PROBLEM

> The current building trend toward lightweight structures, the increasing concentration of dwellings in urban areas, and the increasing noisiness of our environment have led to a growing number of complaints to the FHA of inadequate sound insulation in multifamily dwellings. [Ref. 11]

The increasing noise problem in multifamily dwellings has been a cause for concern among apartment owners, occupants, and investors as well as the government.

> Major property management firms report that noise transmission is one of the most serious problems facing managers of apartment buildings throughout the country.

Managers and owners of apartments readily admit that market resistance is not only increasing as a result of excessive noise transmission, but that lack of both acoustical privacy and noise control are the greatest drawbacks to apartment living. [Ref. 12]

## C. BUILDING STANDARDS

Throughout the United States there are three sets of building codes which establish standards for building design and construction. They are the Basic Building Code, the Standard Building Code, and the Uniform Building Code (UBC). The UBC is the most widely used of the three and is primarily used in the Western United States. Each state adopts one of the codes as the basis for formulating its own state building regulations. California has adopted the UBC.

Noise control standards were not included in the Uniform Building Code (UBC) until the 1973 edition. (It should be noted that an edition of the UBC is not typically adopted by the state or municipality until one to two years after the edition is published. For example, the state of California did not adopt the 1988 edition of the UBC until July, 1989. The 1988 edition was not enforceable at the municipal level until January, 1990.) During 1973, Appendix 35, "Sound Transmission Control" was created for construction of new multiple occupancy buildings such as hotels, dormitories, and apartments. The appendix established minimum interdwelling noise standards which remain in basically the same form today.

Following the publication of the UBC, in 1974 the state of California adopted similar noise insulation standards for new multifamily dwellings. These were rewritten in 1988, approved by the Building Standards Commission, and incorporated into the state building codes in 1989 as promulgated in the California Code of Regulations.

Although the regulations have been in place since 1974, California has been slow to implement multifamily dwelling noise insulation standards. Local building departments, which have approval authority for projects, are typically understaffed and must concentrate on enforcing life safety and health regulations. They do not give enforcement of "quiet" dwelling regulations a high priority. [Ref. 13] Additional reasons have included lack of knowledge on the part of some architects and builders in constructing "quiet" dwellings and a perceived unprofitability for developers in marketing "quiet" dwellings. [Ref. 14] "Noise control is often neglected on the pretext of being too expensive, whereas it really is because there is a fear that it might be expensive."[Ref. 15]

## D. **FUTURE OUTLOOK**

To combat the argument that developers view the provision of sound insulation as unprofitable, a 1967 Federal Housing Administration (FHA) study concluded that the problem is primarily one of noise transmission from one apartment unit to

another within the same building and that a substantial amount of sound insulation could be provided at a relatively low cost through proper planning and design of the building, selection of the building site, building orientation and equipment, and careful design of space layout. [Ref. 16]

D.J. Croome [Ref. 17] argues that only in the years just prior to 1977 did it become the practice to adopt acoustics design as a **consideration** in all buildings, and therefore, there has been little cost experience. He feels that noise control should always be considered even if it is of secondary importance, and that it is not expensive in buildings where energy levels of noise generation are between about 30dBA and 70dBA. Beyond these levels, noise control becomes more expensive, but it is also **critical** at these higher levels in terms of functional and human needs.

The FHA study made an analogy to the architects and builders who see the provision of sound insulation as too costly to their predecessors who voiced the same opinion relative to designing and building into dwellings central heating and air conditioning. Despite the high costs of providing these amenities, they are now considered necessities in office buildings, homes, and automobiles. The study concludes that there is an increasing public demand for the adoption and enforcement of anti-noise ordinances and sound insulation, particularly in multifamily dwellings, and that the public is willing to pay a premium for sound insulated

buildings just as they now do for central air conditioning and heating, spacious rooms, sufficient closet space, and adequate natural lighting.[Ref. 18]

# III. INTERDWELLING SOUND TRANSMISSION

## A. INTERDWELLING SOUND

"Sound is a form of physical energy carried by some medium" [Ref. 19]. Sounds that pass between dwellings through common barriers (hereafter referred to as interdwelling sound), are typically classified by their transmission media as follows:

- Airborne
- Structureborne
- Impact

### 1. Airborne sound

Airborne sound, as its name implies, is sound carried through the air. Air is the most obvious and common of sound transmission paths. The sound follows a line-of-sight air path from the source to the listener. Talking, music, and similar sounds that radiate directly into the air are familiar examples. During its travel, sound is absorbed by the air. "Sound carriers (air in this case) exact their price: the larger the distance the more sound is spent along tne way." [Ref. 20] However, the distances necessary to significantly affect the level of sound cannot be obtained in the typical apartment building. "With the exception of very large

auditoriums, convention halls, or sports arenas, the absorption of sound within buildings or rooms is negligible [Ref. 21]."

### 2. Structureborne Sound

Structureborne sound occurs when walls, floors or other building elements are forced into vibratory motion by direct contact with vibrating sources such as mechanical equipment or domestic appliances. This mechanical energy is transmitted throughout the building structure to other wall and floor assemblies with large surface areas, which in turn are forced into vibration. This vibration is transmitted to the surrounding air, causing pressure fluctuations that are propagated as airborne noise. [Ref. 22]

### 3. Impact Sound

Impact sound is a form of structureborne sound that is limited to the sound generated as a result of an object (foot, box, weight, etc.) striking the surfaces (wall or floor/ceiling assembly) that separates dwellings. This impact causes the surface to initially vibrate. Similar to structureborne sound, the vibration is then transmitted through the member and to other members, and is radiated on the other side as airborne sound.

The most common form of impact sound occurs in the floor/ceiling assembly separating apartments with the sound being generated in the dwelling above. The impact sound is

particularly easy to transmit when the floor and ceiling are rigidly connected, which is commonplace. The construction practice of attaching flooring and ceiling directly to the same joists is often utilized. Theodore Berland in *The Fight for Quiet* [Ref. 23], cites the Construction Lending Guide of the U.S. Savings and Loan League:

> Impact noise caused by a floor or wall being set into vibration by direct mechanical contact is then radiated from both sides. This vibration may also be transmitted throughout the structure to walls and reradiated as sound to adjoining spaces ... footsteps, children romping and playing, and moving furniture on the floors constitute the major impact problem.

#### 4. Discussion

"In most cases noise travels from one point to another via any one or a combination of several such paths." [Ref. 24] A great number of sources exist which will produce both airborne and structureborne noise. A built-in dishwasher for example, will produce airborne sounds from the motor and pump or the sounds of water filling and draining. In addition, the rigid attachment of the machine to the floor or cabinets, and connections to the plumbing system, can induce vibration in the wall, floor and pipes, creating structureborne noise.

In comparing airborne and structureborne sounds, airborne sounds are much easier to attenuate. As stated earlier, considerable energy is dissipated when sound is transmitted through the air. As a result, airborne sound

generated within a building is generally limited to areas near the source. For example, sounds from a television may be heard in the apartment next door, but will probably not be heard in apartments further away (unless there is a path for the sound to travel such as doors and windows open, where it may reflect off of surfaces or diffract and reach listeners further away) [Ref. 25]. Structureborne sound, however, is more easily transmitted because the vibrating member is more efficiently connected to other structural members. "Unlike sound propagated in the air, the vibrations are transmitted rapidly with very little attenuation through the skeletal frame of the building or other structural paths." [Ref. 26]

## B. MEASURING SOUND TRANSMISSION

### 1. Sound Transmission Class (STC) Laboratory Testing

To measure the effectiveness of a material or an assembly of materials, such as a wall or floor/ceiling assembly for its insulation against airborne sound, a number of laboratory and field tests have been established. One of the most common standards used to express the results of these tests is the Sound Transmission Class (STC). The STC develops a single rating for the material's (or assembly's) ability to insulate against airborne sound. The American Society for Testing and Materials (ASTM), Standard Method E 90-83, Standard Classification E 413-73 (1980) has been established

to regulate the performance of this procedure [Ref. 27]. In general terms, laboratory tests for the STC consist of exposing the material to sixteen sound frequency bands, ranging from 125 to 4000 Hz and measuring the sound transmission loss. Analysis of the material's response to the different frequencies is then performed and the STC is established.

2. **Sound Transmission Class (STC) Field Testing**

The STC established in the laboratory may not be representative of the sound transmission actually occurring between the dwellings. The laboratory STC is reasonably accurate, but is only a measure of the test assembly and the actual sound separation from room to room may not align with the laboratory STC. [Ref. 28] This is a result of "sound leaks" or sound that travels over "flanking paths". Flanking paths are indirect transmission paths that the sound may follow.

There are numerous opportunities, particularly when competent construction practices are not followed, for sound leaks and flanking paths to occur. Flanking paths are significant because one of the properties of sound is its ability to diffract, or to bend or squeeze.

> When a sound wave encounters an obstacle or an opening is comparable in size to its wavelength, the sound will bend around the obstacle or squeeze through the opening with little loss of energy... The amount of sound energy that passes through a small hole or hairline crack in a wall is

far greater than one would predict based on the size of the crack. [Ref. 29]

Provided below is an abbreviated listing of possible sources of sound leaks and flanking paths for sound to travel between dwellings [Ref. 30]:

- plenums and suspended ceilings
- unbaffled ducts
- window to window (outdoors)
- common heating units
- transoms and air grilles
- unblocked joist spaces
- uncaulked wall perimeters
- ducts, piping and fixtures
- back-to back electrical outlets
- masonry joints

Field tests measure the sound transmission from room to room regardless of the sound path (directly through the separating partition or along flanking paths). Following similar procedures as required for the laboratory test, the test is performed in the rooms in question and a Field STC (FSTC) is established. Performing this test in an uncontrolled environment requires assumptions to be made regarding sound paths. As stated in the California State Building Code [Ref. 31] "All sound transmitted from the source room to the receiving room is assumed to be through

the separating wall or floor/ceiling assembly". However, the Code requires those performing the test to follow the ASTM Standard Test Method E 336-67T, for the FSTC which requires a check for "**significant** flanking paths". If it is determined that significant flanking paths exist, they must be found and corrected. [Ref. 32]

### 3. Discussion of Laboratory and Field Testing

> Flanking paths and sound leaks do not influence laboratory tests, therefore these tests will not necessarily indicate the amount of noise isolation actually achieved in a completed building. Yet it is the isolation that the occupant is concerned with, not the insulation rating (STC) of the assembly. [Ref. 33]

Field tests will obviously reflect more accurately the conditions to which the dwelling occupant is subjected, but they can only be performed once the construction is complete. Major modifications at that time may not be possible. Additionally, standard wall and floor/ceiling assemblies with established STC ratings (based on previous laboratory testing) can be selected from catalogs before construction. This satisfies the building code and eliminates the cost to the designer or builder of performing any testing, whether performed in the laboratory or in the field. Properly selected assemblies coupled with attention to the elimination of flanking paths and to the details of construction, will serve to better satisfy both the building code and the tenant.

### 4. Structureborne and Impact Sound

Like the STC, the Impact Isolation Class (IIC) is established to provide a single figure rating for floor/ceiling assemblies [Ref. 34]. It represents the assemblies' effectiveness in providing reduction of impact generated sounds such as footsteps and is determined by utilizing a "standard" tapping machine to strike the surface of the floor side of the assembly in accordance with ASTM standard method E 492-77. Sound transmission loss across the same frequency bands as in the STC is measured from directly below the tapping machine on the ceiling side. An analysis of the results is made and the IIC is determined.

The procedure for the laboratory and field tests are similar; however, an allowance is made with the field test for background noise. The building code allows the floor coverings to be used in determining the rating as long as the coverings remain a permanent part of the dwelling. Flanking paths are not nearly as critical to the IIC as in airborne sound because the impact will typically follow a direct path through the assembly.

Aside from providing for insulation against impact sound, other forms of structureborne sounds are not regulated by the current building code. Mechanical equipment found in many multifamily dwellings, such as heating and air conditioning units, pumps, motors, and elevators can be significant sources of noise and vibration. Equipment such as

this must typically be attached to the structure of the building and can easily create high levels of structureborne sound. When designing for the installation of such items, it is left to the architect and builder to ensure competent construction practices are followed to minimize or eliminate structureborne sound. Competent practices, for example, may include using vibration isolators and flexible connections on mechanical equipment, or designing ventilation systems properly to minimize structureborne sound transmission.

## C. INTERDWELLING NOISE REGULATIONS

California, like most western states, has adopted the Uniform Building Code (UBC) to regulate life safety, health, and other occupant welfare issues in building construction. To complement the UBC, the California Building Standards Commission has created the California State Building Code as a forum for developing additions and amendments to the UBC [Ref. 35]

Sound transmission control requirements were first included in the 1973 edition of the UBC [Ref. 36]. Following adoption of the 1973 UBC, the California State Building Code [Ref. 37] established similar standards for interdwelling sound transmission control in multifamily residences in 1974. As stated in both codes:

> Wall and floor/ceiling assemblies separating dwelling units or guest rooms from each other and from public or service areas such as interior corridors, garages and

> mechanical spaces shall provide airborne sound insulation for walls, and both airborne and impact sound insulation for floor/ceiling assemblies.

The standards promulgated for interdwelling sound transmission control by both the UBC and California State Building Codes are nearly identical. The State Building Code provides additional standards for exterior sound transmission control which is not addressed in the UBC nor in this thesis.

The California State Building Code takes precedence over the UBC and, for simplicity, the remainder of this discussion will refer to the State Code. Building codes may also be modified at the county and city level. For the purposes of this thesis, data collection was confined to the City of Monterey, located in the County of Monterey. The city and county have made no amendments or modifications to the State Code regarding interdwelling sound transmission.

**1. Current Regulations**

The State Building Code, as it applies to multifamily dwellings, provides for airborne sound insulation and impact sound insulation. The Code requires the walls and floor/ceiling assemblies separating dwellings to meet or exceed a Sound Transmission Class (STC) rating of 50 or greater, based on laboratory tests. In lieu of the laboratory test, the Code allows a field test to be performed. To allow for background noise, the laboratory STC value of 50 is reduced to a STC of 45 when measured in the field. Entrance

doors from interior corridors must meet or exceed a STC rating of 26. In addition, floor/ceiling assemblies must also meet an Impact Insulation Class (IIC) of 50 or greater. Similar to the STC, a field test may be performed and a field value IIC of 45 or greater is acceptable.

To develop an understanding of what the different STC ratings mean in layman's terms, Table 1 is provided [Ref. 38]:

TABLE 1 - STC & VARIOUS WALL STRUCTURES

| STC RATING | PRIVACY AFFORDED | TYPICAL WALL STRUCTURE |
|---|---|---|
| 25 | Normal speech easily understood | ¼" wood panels nailed on each side of 2x4 studs |
| 30 | Normal speech audible but not intelligible | ⅝" gypsum wallboard nailed to one side of 2x4 studs |
| 35 | Loud speech audible and fairly understandable | ⅝" gypsum wallboard nailed to both sides of 2x4 studs |
| 40 | Loud speech audible but not intelligible | 2 layers of ⅝" gypsum wallboard nailed to both sides of 2x4 studs |
| 45 | Loud speech barely audible | 2 sets of 2x3 studs staggered 8"on centers on 2x4 base with 2 layers of ⅝" gypsum wallboard on each side |
| 50 | Shouting barely audible | 2x4 studs with resilient channels nailed horizontally to both sides with ⅝" gypsum wallboard screwed to channels on each side |
| 55 | Shouting not audible | 3-⅝" metal studs with 3" layer of glass fiber blanket between studs. 2 layers of ⅝" gypsum wallboard attached to each side of studs. |

## D. INTERDWELLING SOUND CONTROL AT MONTEREY PINES APARTMENTS

The Monterey Pines Apartments is an apartment complex with thirty-one buildings containing a total of 286 units. The buildings are made of wood construction and are two and three story structures. All units within the building are single level. The building permit for this complex was approved by the City of Monterey on 1 August, 1972. As previously stated, there were no sound transmission control regulations in place at that time. Specifically, the State Building Code applies to "applications for building permits made subsequent to August, 1974". [Ref. 39]

However, a review of the plans and specifications for the construction of the complex, on file at the City of Monterey Building Department, revealed the designer did consider interdwelling sound control. Walls separating units, referred to as "party walls" by the architect, were constructed differently than other walls. In addition, floor/ceiling assemblies between units were insulated.

### 1. Wall Construction

The "party walls" are constructed on a 2 "x 6" base plate with 2"x 4" staggered-studs. ⅝" Gypsum board is nailed to the studs. Additionally, the specifications require 2" rock wool insulation batts in the walls.

The *staggered-stud* is an interior wall construction technique which eliminates the tendency of walls to transmit noise directly from one room to another. In a typical non-staggered-stud wall, the plaster or wallboard

on each side transmits noise directly from one room to another. In a staggered-stud wall, the plaster or wallboard on each side of the wall is attached only to its own stud. Thus, there is dead space inside the wall, and thus each wall surface can vibrate freely without directly affecting the other. The noise, in effect, spends itself causing the closet wall to vibrate sympathetically.

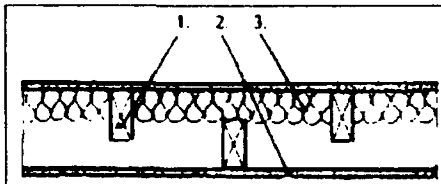
| | | | | |
|---|---|---|---|---|
|   | 1. 2x4 studs spaced 16"o.c. and staggered 8"o.c. on 2x6 plates. 2. 5/8" type X gypsum board screwed 12"o.c. 3. 2" thick sound attenuation blanket. | .. | Owens/Corning Fiberglas OCF 443 1966 16f Owens/Corning Fiberglas | 46 |

**Figure 1** - A wall section similar in construction to the Monterey Pines Apartments, with an STC rating of 46.

The same type of wall construction used at Monterey Pines was tested by Owens/Corning Fiberglas in 1966 and produced a laboratory STC rating of 46 (see Figure 1). This rating is approximately equivalent to the current regulated STC rating of 50 and provides the tenants with a significant amount of sound insulation.

### 2. Floor/ceiling Construction

The floor/ceiling assembly is constructed of 2"x 10" wood joists spaced at 16". The ceiling is ½" gypsum board secured to the joists. The flooring consists of a ⅝" plywood subfloor and a ⅝" plywood floor covered with carpet or vinyl tile. In addition, the specifications require "full thick foil back fiberglass batts between ceiling joists". Although there are no laboratory test results for this exact construction, according to Theodore Berland "Such basic floors have STCs in the mid-30 range, as measured by the National

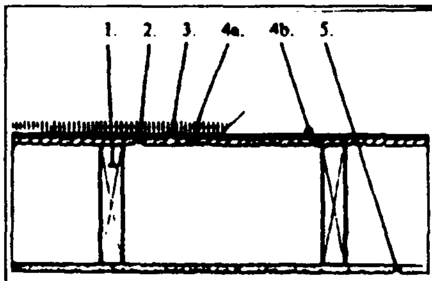
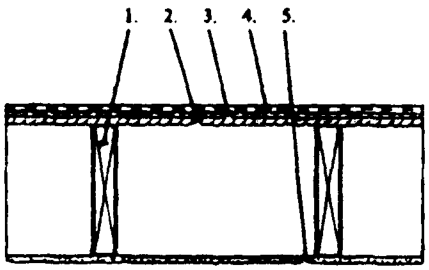
| | | | | |
|---|---|---|---|---|
| <br> | 1. 2x8 joists, 16"o.c.<br>2. 1/2" plywood nailed to joists.<br>3. 3/8" plywood nailed to joists.<br>4a. carpet and pad.<br>4b. no floor covering.<br>5. 1/2" type X gypsum board nailed with 5d nails 6"o.c. | ... | National Gypsum Co.<br>4024<br>5033<br>5032<br>1966<br>16f<br>Gypsum Association | 37<br><br><br><br><br>a. 66<br>b. 32 |
| <br> | 1. 2x10 joists, 16"o.c.<br>2. 5/8" plywood subfloor glued to joists and nailed with 8d nails 12"o.c.<br>3. 1/4" particle board glued to plywood.<br>4. 1/2" parquet wood flooring glued to particle board.<br>5. 1/2" type X gypsum board screwed 12"o.c. | ... | Owens/Corning Fiberglas<br>OCF F-21-68<br>OCF FI-24-68<br>1968<br>16f<br>Owens/Corning Fiberglas | 42<br><br><br><br><br>37 |

**Figure** 2 - Two floor/ceiling assemblies with STC ratings of 37 and 42 respectively

Bureau of Standards" [Ref. 40]. From examining the results of similar constructions in the *Catalog of STC and IIC Ratings for Wall and Floor/ceiling Assemblies*, the STC can be expected to be within the range of 37 to 42 (see Figure 2). The significant factor that contributes most to the low STC rating is that the ceiling and floor are both rigidly connected to the same member (the joist).

The IIC of the floor is primarily dependent on the type of floor covering. "The more it is padded and carpeted, the more 'cushion' a floor has to prevent impact sounds" [Ref. 41]. A floor/ceiling assembly similar to Monterey Pines attains an IIC of 66 with carpet and padding, 32 without [Ref. 42]. The quality of the carpet and pad can

have an effect on the IIC rating (while having little effect on the STC). As an example, tests performed by Owens/Corning Fiberglas found the same assembly can have a 12 point increase in IIC when the 50 oz. carpet and 24 oz. hair pad are replaced by 65 oz. carpet and 30 oz. foam rubber pad. Vinyl tile or ceramic tile found in most kitchens and baths contribute very little to an increased IIC and some tests actually reveal the IIC is decreased by adding such items to the bare floor.

Similar to the wall construction, the floor/ceiling assembly provides a significant amount of sound control. Although with one exception, they do not meet today's standards. The carpeted areas of the apartments most likely meet the current standards for IIC.

# IV. NOISE SURVEY

## A. HYPOTHESES

The questionnaire (see Appendix A) was used in an attempt to identify certain characteristics of the respondents, their attitudes toward noises, and how much they would be willing to pay in addition to their monthly rent to abate these noises. We hypothesized the following:

1. That noise from both inside and outside their apartments would be annoying to them.
2. That interdwelling noise would be more annoying to them than noise from outside their apartments.
3. That their annoyance to noise would be strong enough to influence them to pay an additional amount in rent each month to abate the noise.

These hypotheses are reflected in the questionnaire which was mailed to a stratified sample of tenants from the Monterey Pines Apartments complex at 201 Glenwood Circle, Monterey, CA 93940.

## B. MAIL SURVEY

A mail survey was used to gather our information. Although mail surveys tend to yield a low percentage of returns and relatively incomplete responses, we used the mail survey because it is the most practical and economical method of obtaining data. [Ref. 43] Other advantages to using mail

questionnaires vice personal interviews or telephone surveys are that the respondent can answer the questions at his leisure and provide more accurate data since the questions are in print. Also, mail surveys can be anonymous where confidential returns are secured and areas which are not subject to direct observation (which may bias the responses) such as awareness, attitudes, and intentions are covered. [Ref. 44]

The survey was mailed to thirty respondents with a response rate of fifty percent, which is considered a favorable response rate for a mail survey.

> The literature reports mail survey return rates that are as low as 15 percent (far lower than in personal interviews or telephone surveys) and as high as 95 percent... Although it is difficult to generalize, a response rate of 40 to 50 percent is a typical range in marketing surveys. [Ref. 45]

Several steps were taken to increase the response rate from those surveyed. A cover letter was sent with each questionnaire and was written and constructed so that it was both personal and easy to read. The addresses on the envelopes for the survey were hand written and the cover letters attached to each questionnaire were signed personally. Preaddressed, prestamped envelopes were included in the package sent to each respondent. Uhl and Schoner [Ref. 46] point out that very subtle obligating techniques increase responses, such as the fact that recipients of mail questionnaires feel more obligated to

respond when preaddressed, prestamped envelopes are used. They also state that if adequate attention is given to the details that help to increase the return rate, few surveys yield return rates under forty percent.

The purpose of our study was explained in the cover letter and a guarantee of anonymity was given (see Appendix D).

> Obtaining cooperation from the recipient of a mail questionnaire is difficult; however, a carefully worded cover letter has been found to be helpful... In soliciting the respondents's cooperation, he should clearly understand the manner in which the information that he gives will be used. The respondent should be assured of the confidential nature of the study and that his response will have complete anonymity. [Ref. 47]

## C. QUESTIONNAIRE DESIGN

### 1. Layout

The questionnaire was seven pages long and was designed in format to convince the reader that it was easy to answer. Since the design, wording, and logical ordering of the questions influence the degree, quality, and rating of response, short answer nominal questions were introduced at the beginning, interspersed in the middle with longer questions, and then placed at the end of the questionnaire to facilitate a smooth transition in finishing the survey. [Ref. 48] The position of the questions in relation to each other can affect the responses. It is, therefore, best to keep the first few questions simple and easy to answer.

Respondents tend to become discouraged when they have to answer difficult questions at the start. [Ref. 49]

> Question sequence, like general form, makes a difference in recipients' understanding of what is being sought, in their willingness to be respondents, and even in their ability to respond...the most difficult task is to get the recipients started, but a start does not assure a successful completion. This is why the entire instrument must present a continuous flow. [Ref. 50]

Personal questions were placed at the end of the questionnaire so as not to discourage respondents at the outset from completing the survey.

> Many practitioners are convinced that it is wise to leave the more personal questions (questions regarding age, income[1], etc.) until the end of the interview. Such questions may provoke the respondent and result in an uncooperative attitude or a refusal. If these questions are asked at the end of the questionnaire and create an uncooperative attitude, the information secured prior to those questions will be valuable data. [Ref. 51]

A pretest of the questionnaire was performed where non-response questions and other anomalies were discovered and corrected. According to Drake and Millar [Ref. 52], no market researcher can develop a questionnaire so well that a pretest will not develop some improvements.

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[1] Our target population at the Monterey Pines Apartment complex is a relatively homogeneous group with respect to social class and income characteristics. Since the tenants' willingness to pay for sound insulation can be expected to vary with household income, it was especially valuable to estimate the income of this (homogeneous) group, which was asked in question 23.

### 2. Question Types

The questionnaire was composed of twenty-six directly asked nominal, rating scale, and semantic differential questions which were designed to obtain a mixture of objective and subjective information regarding those variables which were hypothesized to affect the annoyance levels of certain noises and what people were willing to pay to abate those noises.

#### *a. Nominal Scale*

Several nominal questions were asked which required the respondent to simply answer "yes or no" or check the appropriate box or line. Nominal questions are useful only in identifying respondents with certain categories and characteristics. They are simple to answer and require little thought on the part of the respondent. They allow the analyst to simply **count** the numbers of respondents in a certain category predesigned into the question. They do not measure the attitudes or intensity of feeling toward a certain stimulus. Questions asked of a nominal scale were ones such as age, income, sex, marital status, and whether a respondent lived in an upstairs or downstairs apartment.

#### *b. Semantic Differential and Rating Scales*

The semantic differential and rating scales are two of the most popular scaling techniques. They enable the analyst to probe attitudes regarding both content and

intensity to the question asked by using a balanced scale.

> As an advocate of scaling techniques, Louis Guttman believes consumer attitudes have at least two points. These points are identified as *content* and *intensity.* Content refers to a respondent's agreement or disagreement with an idea or a statement. Content may be measured by a "yes" or "no" response to a question. This is a quantitative measurement. *Intensity* refers to the strength of the respondent's feeling regarding the answer to a question. One respondent may respond to a question in a hesitating manner with the phrase "Well, I think so." Another respondent may very quickly say, "Yes, definitely so." [Ref. 53]

According to Drake and Millar [Ref. 54], scaling techniques attempt to measure the intensity of the respondent's feelings about his or her answer. They also allow the respondent more freedom in expressing his or her feelings and give a more precise classification of responses. [Ref. 55]

For semantic differential questions, the respondent of the questionnaire is shown a set of bipolar adjectives. In the survey for this thesis, for example, the bipolar adjectives are:

Not Influential ..... Very influential

Not Annoying ........ Very Annoying

Each adjective pair is usually separated by a continuum on which equal steps are marked off with the following descriptors:

Extremely..Very..Slightly...Both...Slightly...Very...Extremely

For each adjective pair (Influential ... Not influential, Annoying ... Not annoying), the respondent is asked to score his or her attitudes about the stimulus by checking the appropriate intensity interval for each adjective pair. [Ref. 56]

> For rating scales, a respondent rates his or her reaction to certain stimuli on series of equal appearing intervals ranging from extreme dislike to extreme like. Some of these scales can yield as many as 17 to 21 intervals. [Ref. 57]

In determining the scale values in the questionnaire in thesis, the equality of the interval intensities were subjectively made equal. This is normal procedure in practice; However, according to Green and Frank [Ref. 58], there is always some question as to whether or not these intervals can actually be made subjectively equal. Drake and Millar [Ref. 59] also allude to this difficulty by stating, "We should not overlook the difficulty of finding expressive phrases that describe the respondent's possible feelings with the equal intervals between the classifications." [Ref. 60].

In determining the number of intervals, no more than seven were used since most people can identify with no more than seven.

> Although some rating scales are designed to yield as many as 17 or 21 intervals, it is questionable whether respondents can rate stimuli on such a detailed basis.

> Miller [137], in summarizing a variety of experiments dealing with people's ability to make absolute judgments, indicates that most persons can only identify about seven gradations of a specific stimulus. It is not surprising, then, that many rating procedures involve at most a 7-point scale. [Ref. 61]

The three types of scales used in the questionnaire used closed-ended questions vice open-ended questions because the results of closed-ended questions are more easily analyzed than open-ended questions. Closed-ended questions suggest an answer and may inject bias into the answer as well as present the danger of providing too few or too many choices for answers. [Ref. 62] Also, a provision for an indefinite response such as "can't hear" and "neutral" as well as one for "fill-in" answers was provided, which according to Drake and Millar [Ref. 63] is a wise thing to do when using closed questions. It gives the respondent an "out", but according to Seibert and Wills [Ref. 64], it can also give the respondent a tendency to seek a middle ground when answering a question.

## D. FREQUENCY ANALYSIS

Frequency analysis was used as the primary method for aggregating and interpreting responses to the survey and for drawing conclusions from the survey. The frequency analysis, located in Appendix C, identifies percentages of responses from the variables in each question and indicates the frequency of occurrence for each response.

## E. DATA INTERPRETATION

### 1. General

From the frequency analysis a number of general characteristics of the randomly selected tenants were developed. For instance, none of those surveyed have children living with them, although two-thirds of the respondents are married. Most of the respondents (93%) have family incomes above $20,000 with 62% of the tenants completing the survey being male. The ages of the respondents range from 18 to over 65 with 73% of the respondents between the ages of 18 and 35. 60% of the tenants live in one bedroom, one bath apartments and 73% of those surveyed live in downstairs apartments. Every tenant surveyed shares a common wall with a neighbor and has a neighbor living either above, below, or both above and below him or her.

There are no significant trends in the data to make a correlation between age or marital status, and willingness to pay or levels of annoyance to noise.

### 2. Levels of Annoyance To Noise

An overview of the survey results indicates all respondents are sensitive to various noises regardless of their source, and their degree of annoyance depends on the time of day it occurs. Responses to questions four and 14 show tenants are most annoyed by noise during the mid-week evenings and early mornings.

Loud airborne noises emanating from inside adjoining apartments are most annoying. For instance, arguments, music playing (presumably loud), parties, and dogs barking combined to make 39% of the sounds tenants ranked *most annoying* in question 11 of the survey. Doors & windows opening/closing, which is most likely a combination of airborne and structureborne sound, is also very annoying (23% of those surveyed ranked this *most annoying*).

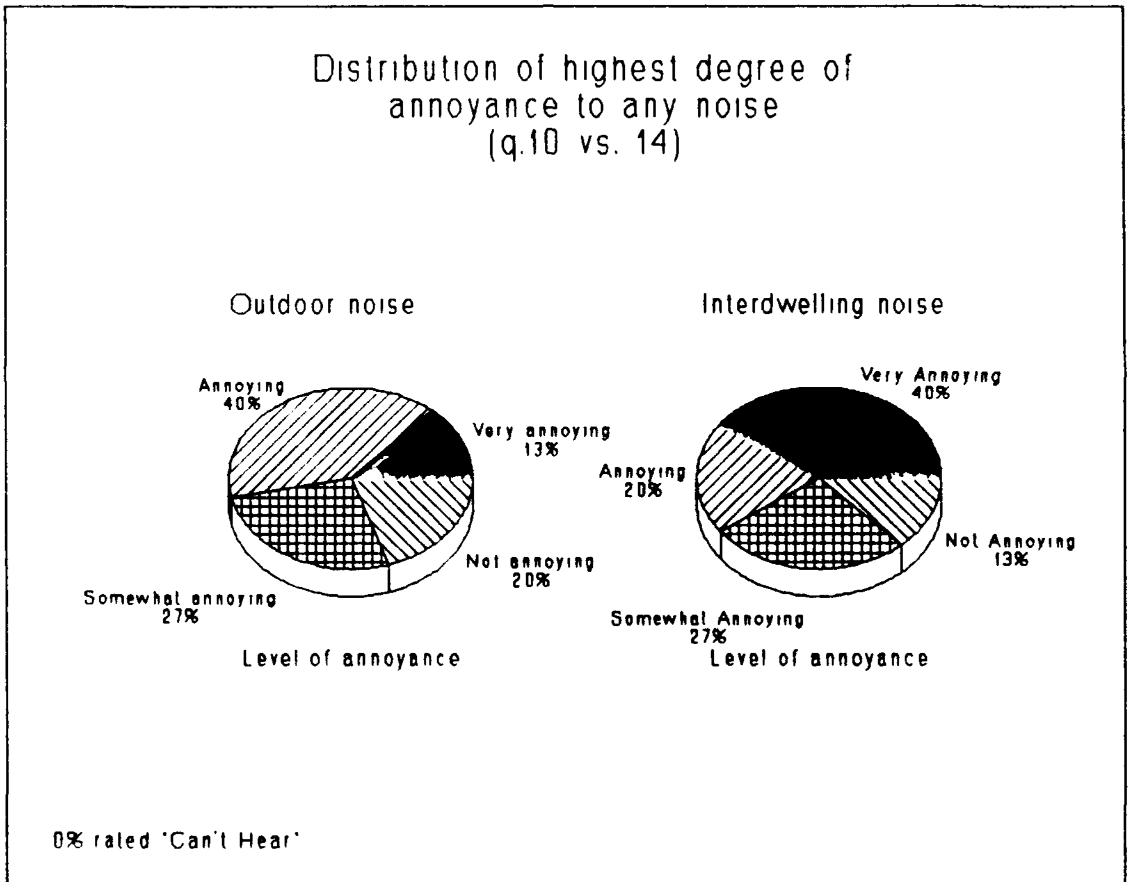



**Figure 3** - Comparison of responses to questions 10 and 14.

Figure 3 was developed to show that annoyance to noise is not just among a small minority of respondents. 87% of the

tenants surveyed were annoyed by interdwelling noise to some degree where 40% of them found an interdwelling noise to be *very annoying.* To a lesser extent, outdoor noise was also annoying with 80% of the respondents indicating some level of annoyance; however, only 13% were *very annoyed* by outdoor noise.

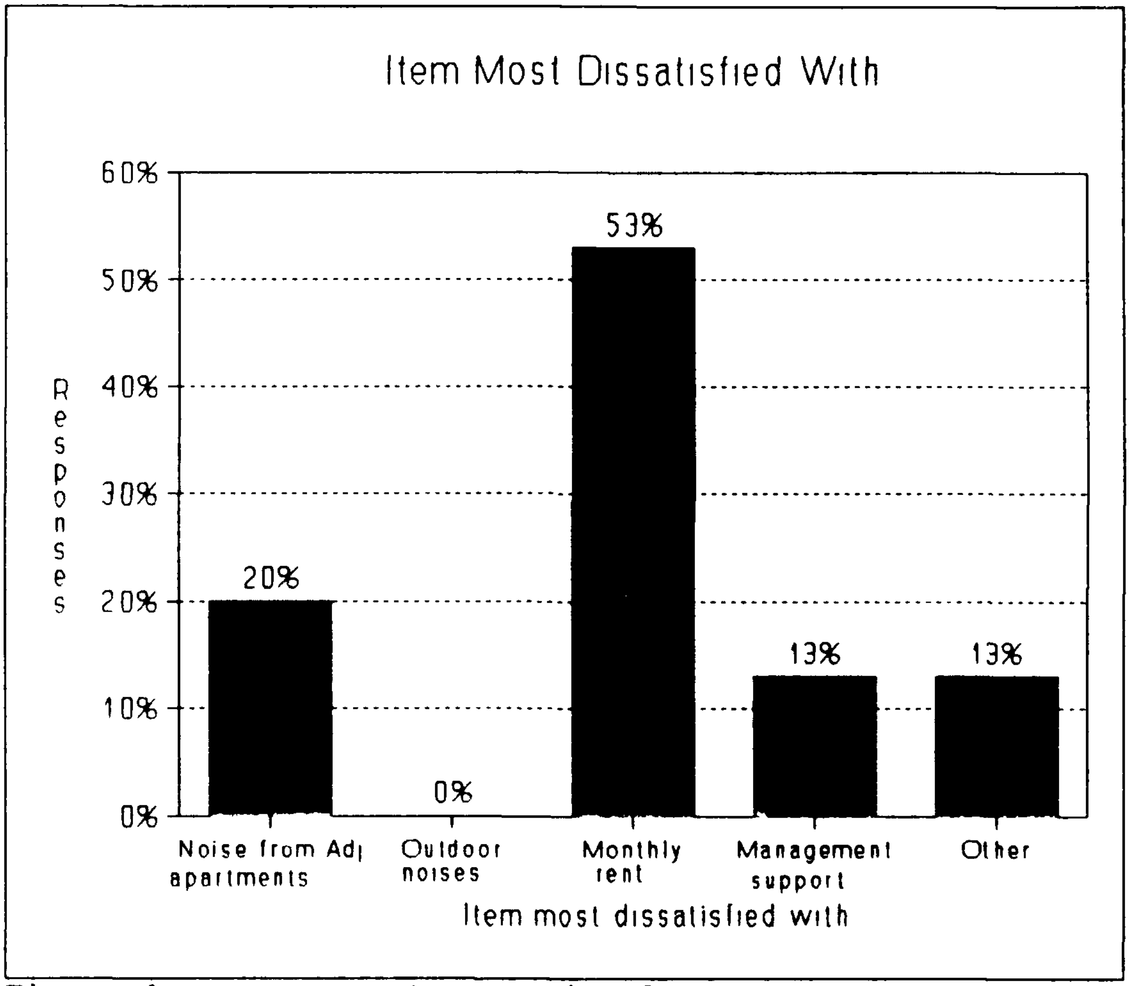



**Figure 4** - Responses to question 8.

As shown in Figure 4, responses to question 8 show that noise from adjoining apartments ranked second only to the

monthly rent amount as the item with which respondents were most dissatisfied.

### 3. Influence of Quiet Surroundings

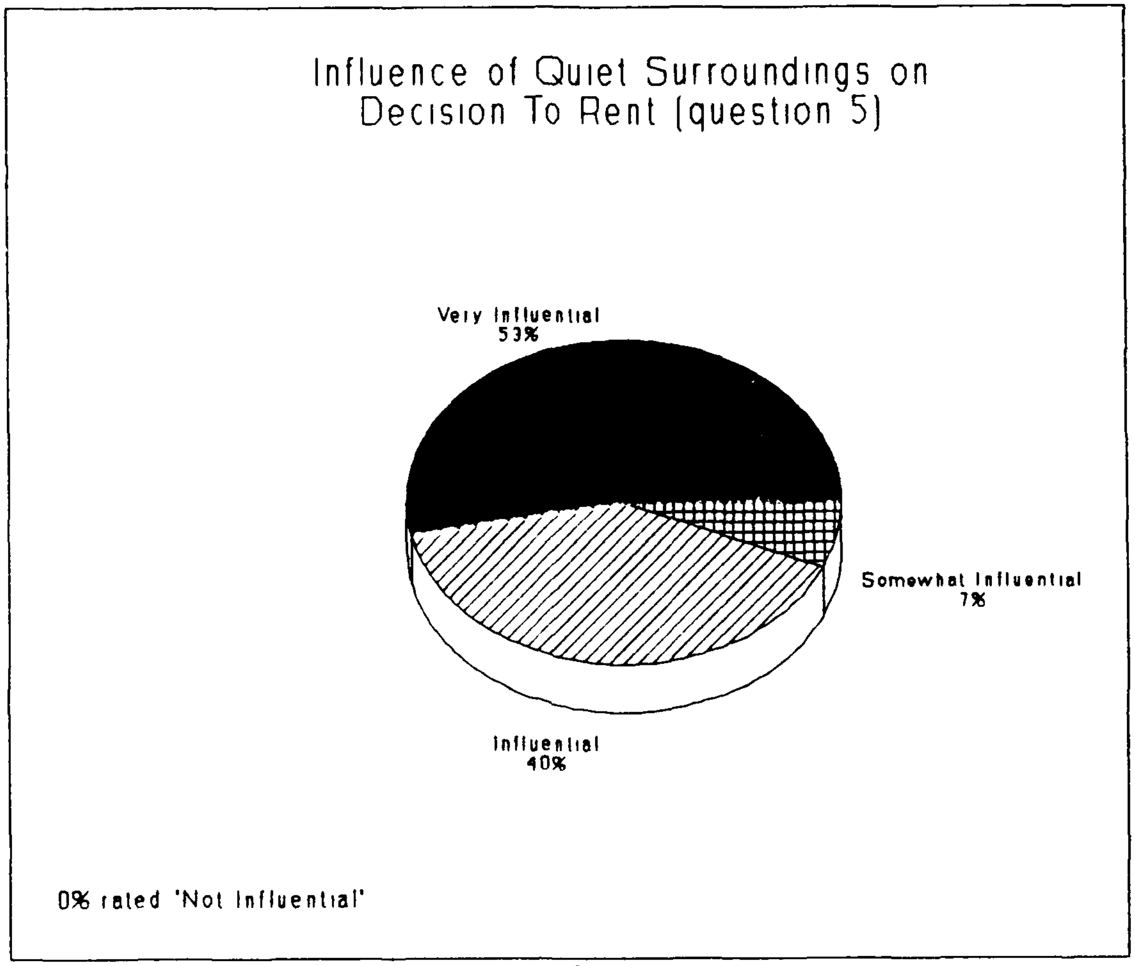



**Figure 5** - Responses to question 5

To support the belief that a peaceful environment is an important consideration in renting an apartment, responses to question 5 (see Figure 5) shows that 93% of the respondents rated quiet surroundings as either *influential* or *very influential* in their decision to rent (53% *very influential* and 40% *influential*). The remaining 7% felt quiet

surroundings were *somewhat influential* and none felt they were *not influential* in their decision to rent.

### a. *Interdwelling Noise vs. Quiet Surroundings*

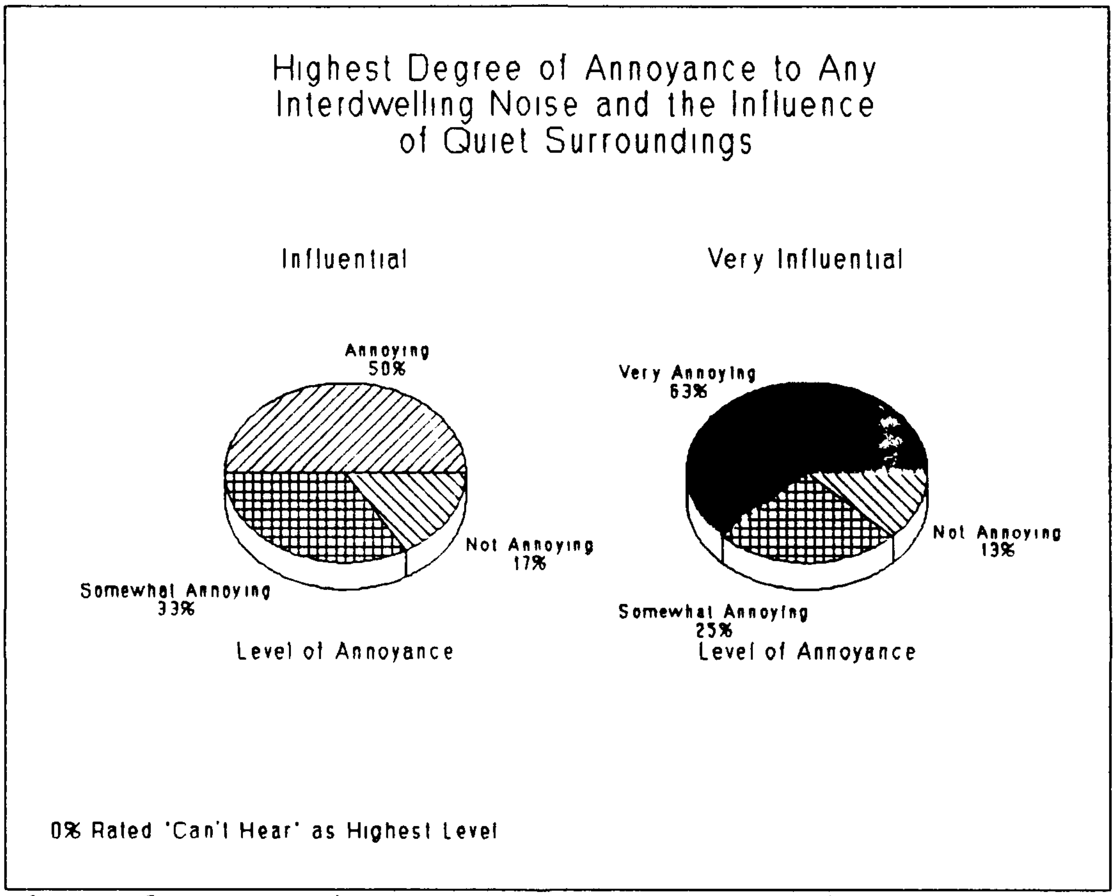



**Figure 6** - Comparison of responses to questions 5 and 10

Tenants who felt quiet surroundings were *very influential* in their decision to rent were the only respondents who ranked any interdwelling noise as being *very annoying* (a comparison of questions 5 and 10 as shown in Figure 6). Those tenants who rated quiet surroundings as *influential* did not rank any interdwelling noise as being *very*

*annoying* but were nevertheless bothered to a relatively high degree by some noise, with 50% being *annoyed* by some noise. This figure reveals that the majority of those surveyed who felt that quiet surroundings were important (93% rating *influential* or *very influential* from Figure 5) were also bothered to a high degree by some noise from adjoining apartments (*annoying* or *very annoying*).

In comparing the two pie charts in Figure 6, the distribution of levels of annoyance is similar between them. The majority of respondents who rated quiet surroundings as *influential* were the ones who thought interdwelling noises were just *annoying*. A similar proportion of tenants who rated quiet surroundings as *very influential* ranked their level of annoyance to any interdwelling noise as *very annoying*. This parallel between the pie charts may indicate a small degree of difference between those who are *very annoyed* and those who are just *annoyed*. The differences in responses may lie in the interpretation of the degree of intensity or the equality of the interval between *annoying* and *very annoying* as well as between *influential* and *very influential*.

Figure 7 shows the dissatisfaction level that respondents expressed with noise from adjoining apartments and demonstrates there is an almost equal distribution of satisfaction levels among those tenants who rated quiet surroundings as *very influential*. However, the revealing conclusion from this table is the fact that these tenants were

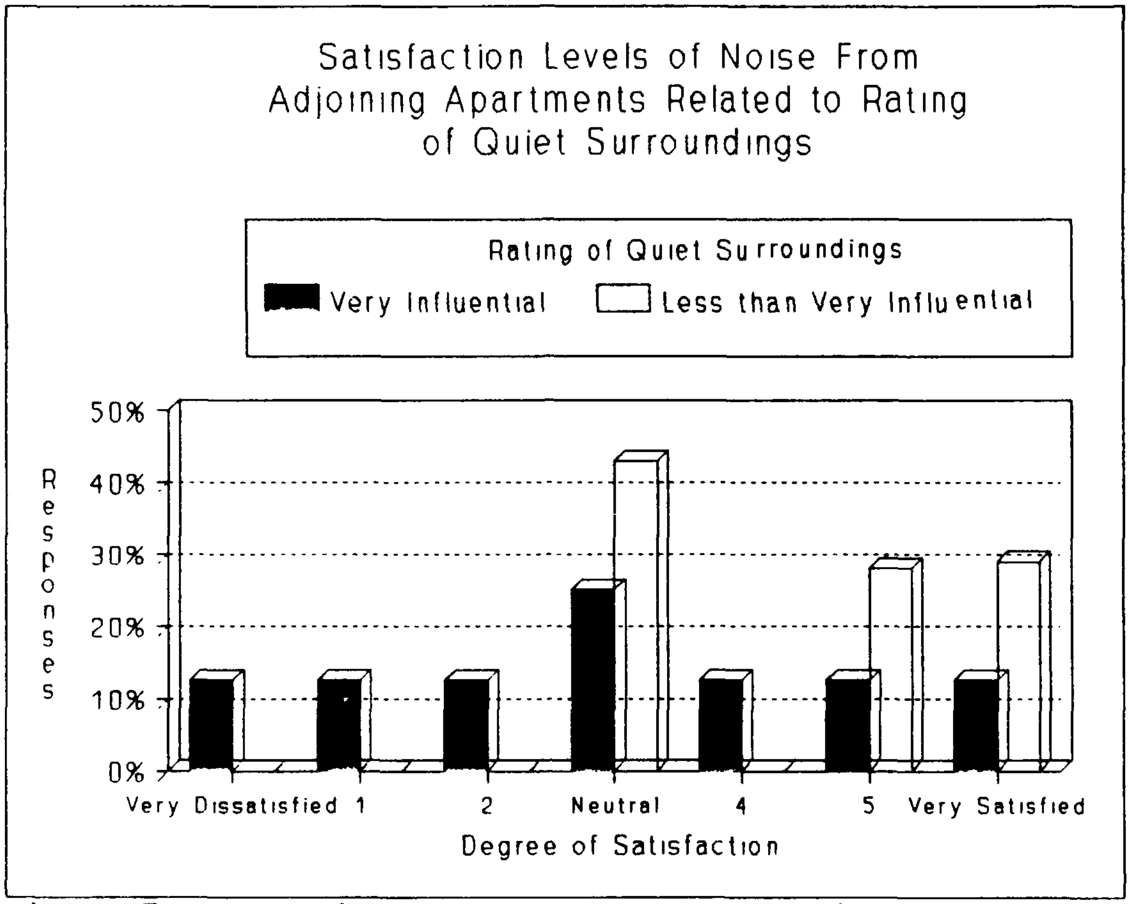



**Figure 7** - Comparison of responses to questions 5 and 7

the only respondents to rate the noise from adjoining apartments in the dissatisfied range. The respondents who rated quiet surroundings less than *very influential* marked their responses in the neutral to very satisfied range showing their general satisfaction with the levels of noise from adjoining apartments.

*b. **Outdoor Noise vs. Quiet Surroundings***

A similar conclusion to that reached from Figure 6, which compared the influence of quiet surroundings and **interdwelling** noises, can be made between the influence of

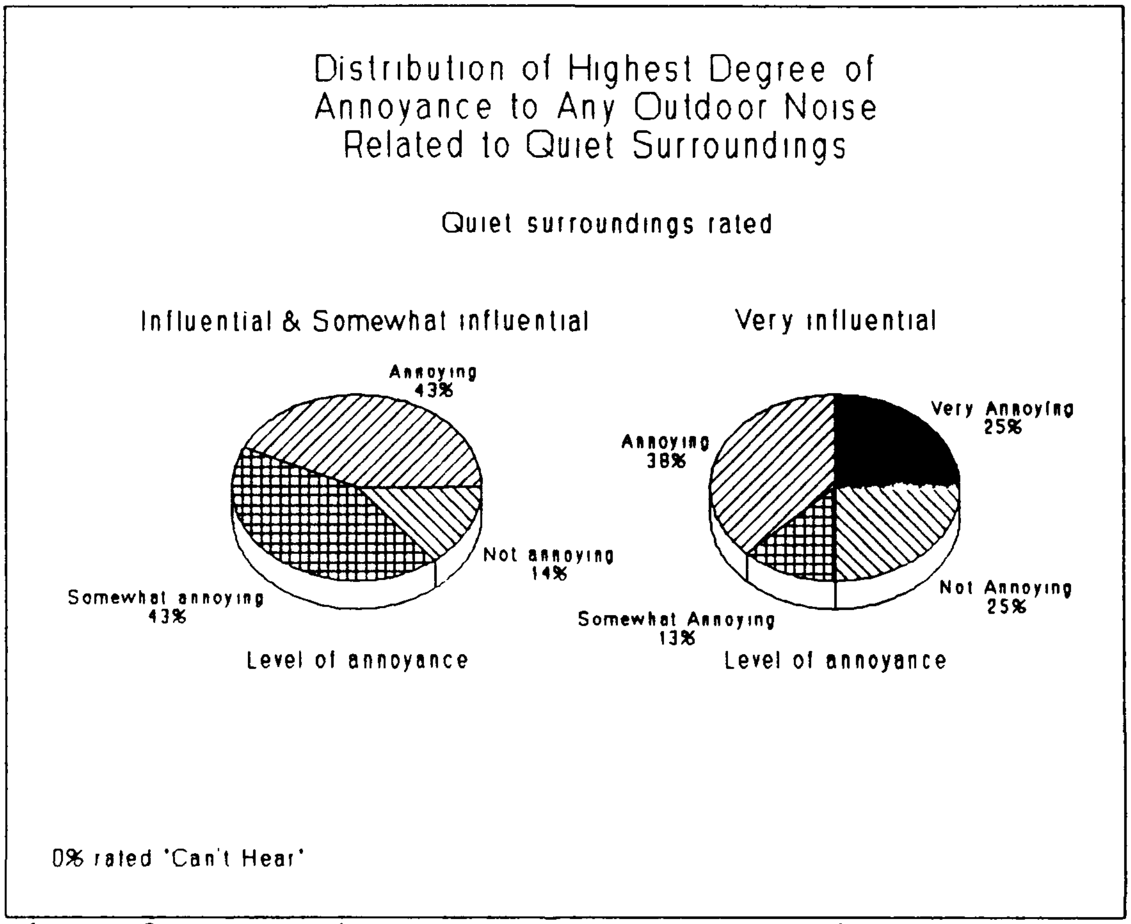



**Figure 8** - Comparison of responses to questions 5 and 14

quiet surroundings and **outdoor** noise by relating the responses to questions 5 and 14 (see Figure 8). The parallel in the distribution levels of annoyance to outdoor noise related to quiet surroundings is similar in proportion and there may not be a large degree of difference between those who are *annoyed* and those who are *very annoyed.* Again, the differences in the responses might be in the interpretation of the degree of intensity or the equality of the interval between *annoying* and *very annoying* as well as *influential* and *very influential.* There is, however, a smaller number of tenants who are *very*

*annoyed* by outdoor noise and a larger portion who are less than *very annoyed* or not annoyed at all by an outdoor noise compared to an interdwelling noise.

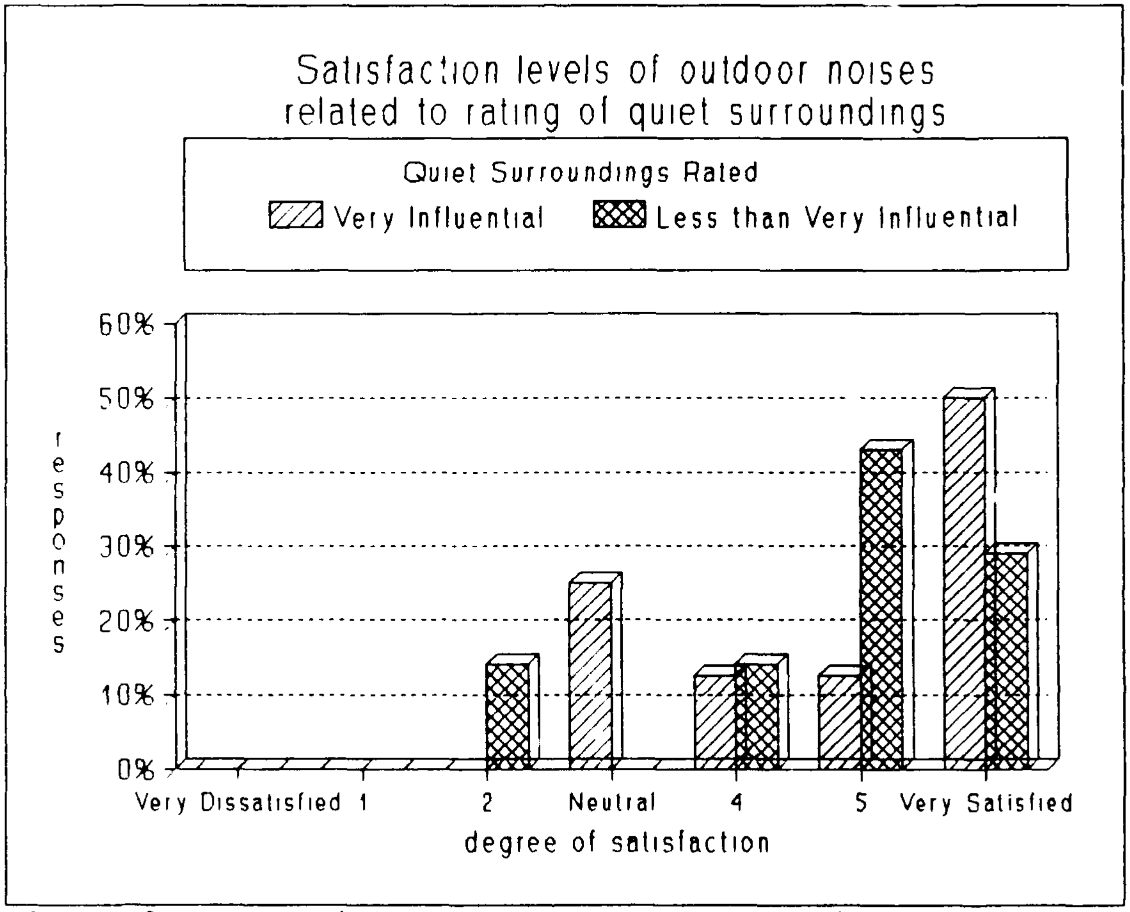



**Figure 9** - Comparison of responses to questions 5 and 7.

Figure 9 more succinctly reveals that outdoor noise seems to be less bothersome to most tenants than interdwelling noise. All respondents who rated quiet surroundings as *very influential* also rated their level of satisfaction with outdoor noises from *neutral* to *very satisfied*. Those respondents who rated quiet surroundings anything less than

*very influential* also rated their degree of satisfaction with outdoor noises from close to *neutral* to *very satisfied.*

**4. Interdwelling and Outdoor Noise vs. Quiet Surroundings**

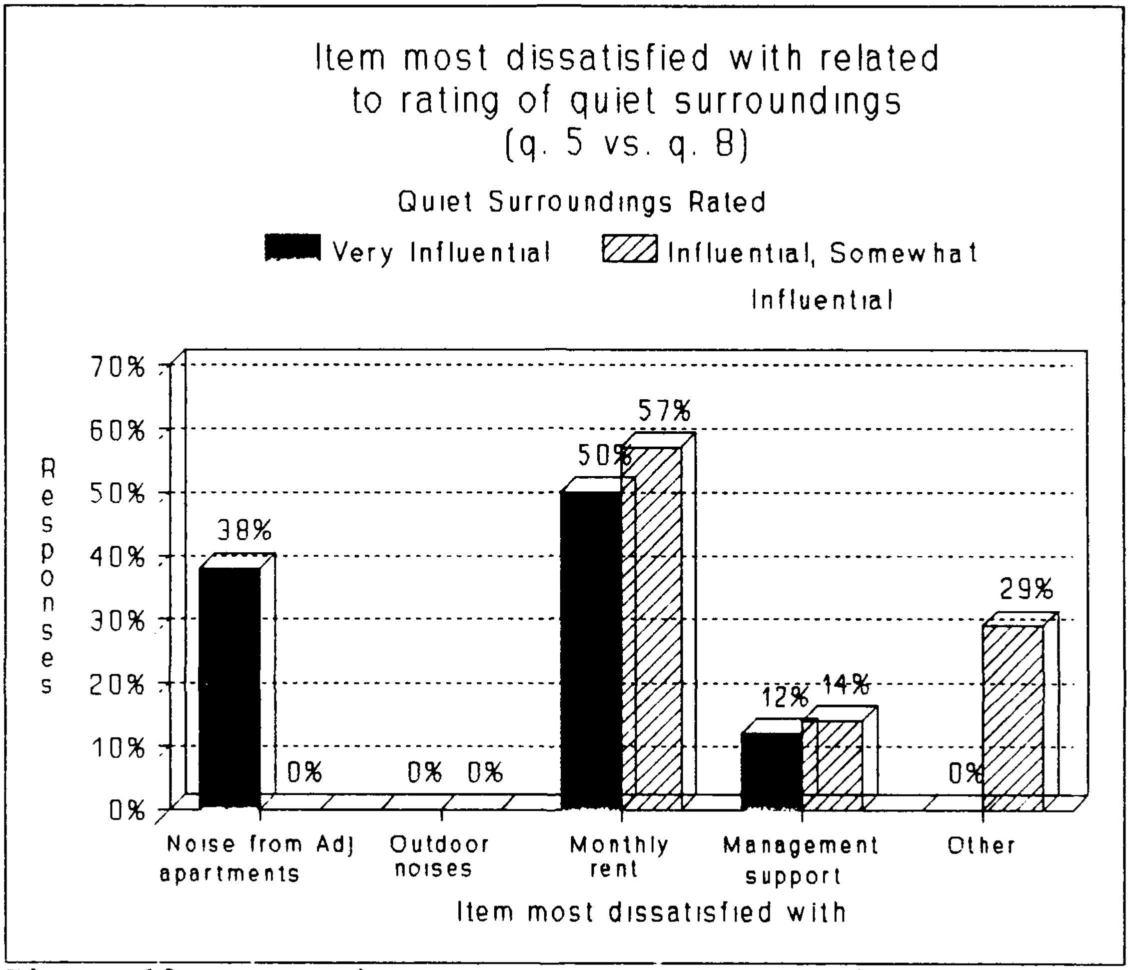



**Figure 10** - Comparison of responses to questions 5 and 8.

The hypothesis that interdwelling noise is more disturbing to tenants than noise from outdoors can also be inferred from Figure 10. Of the respondents who marked quiet surroundings as being *very influential* in their decision to rent, 38% of them were most dissatisfied with noise from adjoining apartments and none were dissatisfied with noise

from outdoors. Of the respondents who rated quiet surroundings as something less than *very influential*, they all rated something other than either outdoor noise or noise from adjoining apartments as the item with which they were most dissatisfied. Regardless of the importance placed on quiet surroundings, the majority of the respondents were most dissatisfied with the monthly rent amount (50% of respondents who marked quiet surroundings as *very influential*, and 57 % of those who rated quiet surroundings as something other than *very influential*).

5. **Interdwelling Noise vs. Outdoor Noise**

The trend in the data from the previous analyses has suggested that the majority of respondents are not as bothered by outdoor noises as they are by interdwelling noises. This trend is substantiated even more by comparing the responses to the first two items listed in question 9 to each other, which reveals that respondents are relatively more disturbed by noise from adjoining apartments than noise from outdoors (see Figure 10). A ranking of very dissatisfied was marked for noise from adjoining apartments where the most dissatisfying mark for outdoor noise was somewhat below neutral. From Figure 4 (responses to question 8) none of the tenants ranked outdoor noise as being the item with which they are most dissatisfied.

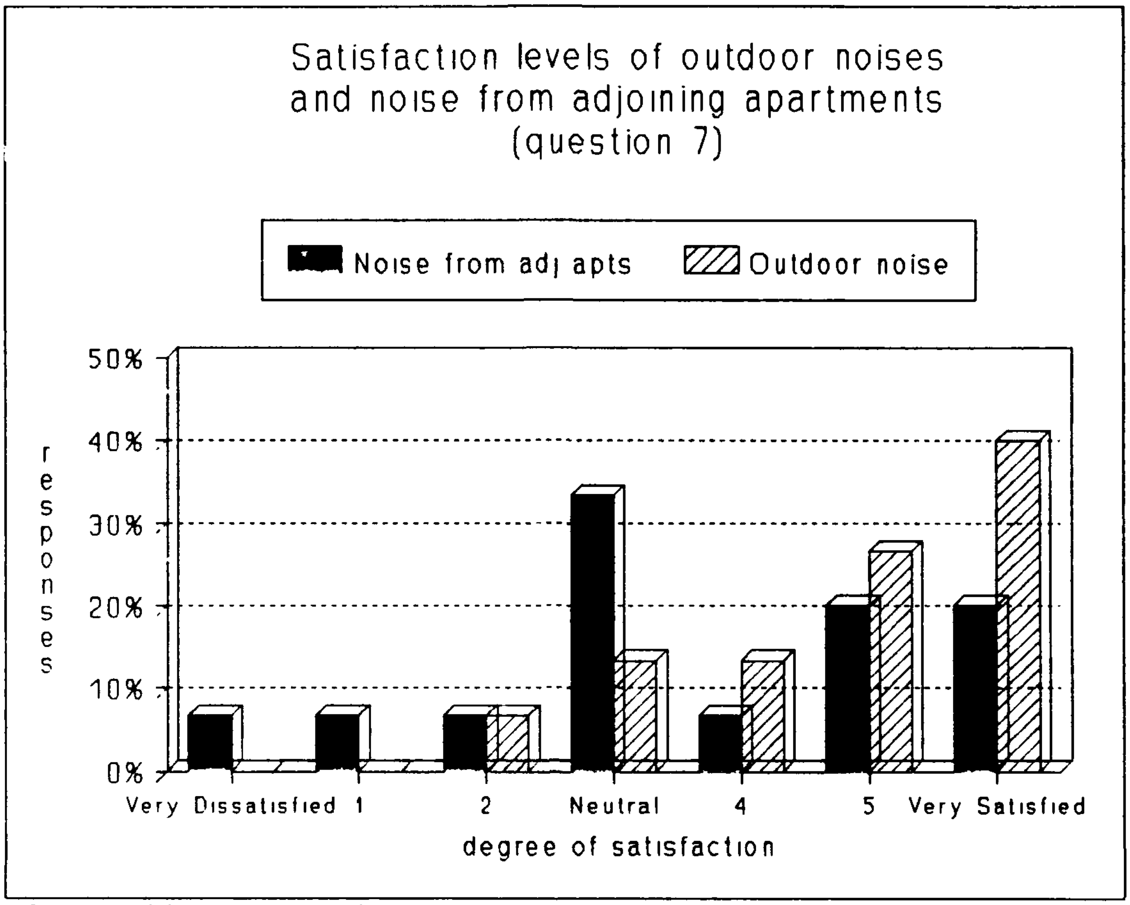



**Figure 11** - Comparison of responses to question 7

Just because the greater portion of respondents are not as annoyed by outdoor noise as they are by interdwelling noise may not mean that outdoor noise is less bothersome. Tenants may have become accustomed to certain outdoor noises at this particular complex or there may be a serene environment surrounding the complex with few outdoor noises at an annoying level. The conclusion that outdoor noise is less annoying than interdwelling noise depends on the environment. These same respondents may or may not be more annoyed by outdoor noises elsewhere.

## 6. Willingness to Pay

### *a. General*

Responses to question 13 show that the majority of respondents are willing to pay for sound insulated apartments with 74% of the tenants willing to pay some amount ranging from $1 to over $20 in additional monthly rent. Twenty percent of the respondents were willing to pay an amount over $20.

Twenty-six percent of those surveyed responded they would not be willing to pay an additional amount in rent for a sound insulated apartment. These individuals were all not satisfied with their apartments based on their answers to question six. From their responses to question eight, their dissatisfaction with their apartments was primarily due to monthly rent amount and management's responsiveness and support.

Those respondents not willing to pay rated noise from adjoining apartments and outdoor noise in the *neutral* to *very satisfied* range in their answers to question seven. The majority of their responses to questions ten and 14 (the level of annoyance from interdwelling and outdoor noise, respectively) were in the lower end of the scale where most responses were rated from *can't hear* to *somewhat annoying*. However, two of the respondents rated some noise as either *annoying* or *very annoying* and were still not willing to pay.

This is inconsistent with the trend of most responses from those who are annoyed by a noise where they are willing to pay to attenuate the noise.

The inference is that these tenants feel a peaceful environment is important (all tenants rated quiet surroundings as either *influential* or *very influential* in their decision to rent) and are bothered to some degree by noise (mostly interdwelling noise), but that the annoyance is not great enough to induce them to pay an additional amount each month to abate the noise.

*b. Gender Correlation*

The data seems to suggest a correlation between the sex of the tenant and the following with regard to willingness to pay:

- All those willing to pay $20 or more are male, and they all found some noise to be *very annoying*. The remainder of the males are willing to pay between $5 - 20 with only one willing to pay between $1 - 5.
- All but one female are not willing to pay any amount for a sound insulated apartment. The remaining female is only willing to pay between $1 - 5. Additionally, the females appear to be less annoyed by noise (based on responses to question 10) with only one of them finding some noise to be *very annoying*.
- There is no indication that the unwillingness to pay by the females is income sensitive. All respondents (both male and female combined) but one (a female) had incomes above $20,000. The female exception had an income below $20,000 and was not willing to pay.

### *c. Living Upstairs vs. Downstairs*

A comparison between living upstairs versus downstairs shows that all those willing to pay over $20 lived in a downstairs apartment. Additionally, in response to question 3, these same individuals feel that noise emanating from the apartment upstairs was more easily heard than noise from the apartment next to them. The majority of people living downstairs who were willing to pay a lesser amount also found noise from the upstairs apartment was more easily heard than the apartment attached side by side. One tenant had an apartment below him as well as above and stated in question 3 that noise from the apartment below him was most easily heard.

Of those respondents who lived in an upstairs apartment, 25% feel that the most annoying source of noise comes from the apartment below. Fifty percent feel that the most annoying noise comes from the apartments attached side-by-side. Another 25% feel that there is no difference between noise emanating from either a downstairs or a side-by-side apartment.

The significance of the responses to question 3 is that noise from above or below tenants seems to be more annoying than noise from attached apartments, which falls in line with the lower STC values calculated for the floor/ceiling assembly versus the "party" wall as discussed in Chapter 3. The importance of this is that a majority of tenants may be satisfied by providing additional sound

insulation for only the floor/ceiling assembly instead of both the floor/ceiling assembly and the walls. This would further reduce the cost to the owner of providing the added sound insulation and increase the benefit/cost ratio.

***d. Willingness to Pay vs. Quiet Surroundings***

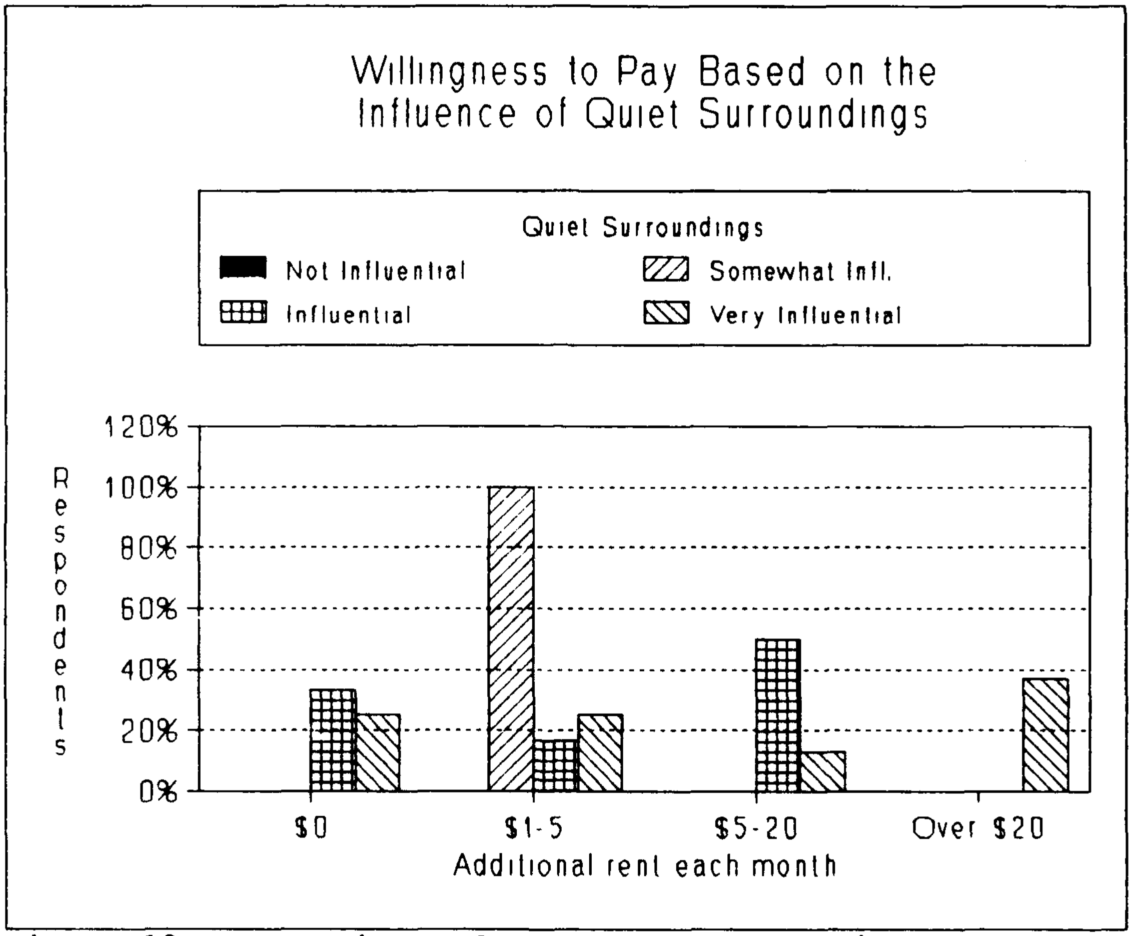



**Figure 12** - Comparison of responses to questions 5 and 13.

Figure 12 shows that the majority of respondents who rated quiet surroundings as *somewhat influential* to *very influential* were willing to pay some amount in additional monthly rent. Thirty-seven percent of those who rated quiet

surroundings as *very influential* were willing to pay over $20 while no tenants who rated quiet surroundings as less than *influential* were willing to pay over $20. Only those tenants who rated quiet surroundings as either *influential* or *very influential* were willing to pay between $5 and over $20.

The trend seems to be that those who rated quiet surroundings as *influential* or *very influential* were also bothered to a great degree by some noise (mostly interdwelling noise). Those who did not rate quiet surroundings as *very influential* in their decision to rent were not as willing to pay for added sound insulation.

***e. Willingness to pay and level of annoyance to Interdwelling Noise***

Table 2 correlates willingness to pay for added sound insulation to the level of annoyance tenants have to any interdwelling noise. A somewhat direct correlation seems to exist between the level of annoyance and the amount respondents are willing to pay in additional monthly rent for noise insulation. Those who ranked *not annoying* were either not willing to pay or only willing to pay up to $5. The respondents who ranked *somewhat annoying* and *annoying* were either not willing to pay or only willing to pay an amount less than or equal to $20. Twenty percent of those surveyed ranked an interdwelling noise as *very annoying* and were willing to pay over $20. This is significant because out of

the 34% of those surveyed who found an interdwelling noise to be *very annoying*, the majority (20% out of the 34%) were willing to pay over $20 and 7% were willing to pay between $5 and $20. Only 7% were not willing to pay anything.

TABLE 2 - COMPARISON OF RESPONSES TO QUESTIONS 10 AND 13.

| Amount Willing to pay | Highest degree of annoyance to any interdwelling noise (% of total respondents) | | | |
|---|---|---|---|---|
| | Not Annoying | Somewhat Annoying | Annoying | Very Annoying |
| $0 | 7% | 7% | 7% | 7% |
| $1 - 5 | 7% | 13% | 7% | |
| $5 - 20 | | 7% | 13% | 7% |
| Over $20 | | | | 20% |

Additionally, all the respondents that ranked *noise from adjoining apartments* on question eight as being the aspect with which they are *most dissatisfied* are willing to pay over $5. Of that group, 67% were willing to pay over $20.

***f. Willingness to Pay and level of annoyance to outdoor noise***

Although a general trend seems to exist between the level of annoyance to outdoor noise and willingness to pay, a useful analysis of Table 3 can be made by comparing it to Table 2. In comparing the tables, everyone that would pay over $20 in Table 2 found a noise from an adjoining apartment *very annoying*, yet only one of them found an outdoor noise to be *very annoying*. The 20% who were willing to pay between $5

and $20 and found an outdoor noise *annoying* were relatively bothered to the same degree by interdwelling noise. The interdwelling noise may be the driving factor influencing their willingness to pay.

TABLE 3 - COMPARISON OF RESPONSES TO QUESTIONS 13 AND 14.

| Amount Willing to pay | Highest degree of annoyance to any outdoor noise (% of total respondents) | | | |
|---|---|---|---|---|
| | Not Annoying | Somewhat Annoying | Annoying | Very Annoying |
| $0 | 7% | 7% | 13% | |
| $1 - 5 | 13% | 7% | | 7% |
| $5 - 20 | | 7% | 20% | |
| Over $20 | | 7% | 7% | 7% |

Overall, consistencies in the data seem to suggest a direct relationship between the importance placed on a peaceful environment and level of annoyance to noise (especially interdwelling noise), and willingness to pay for added sound insulation. This supports the validity of the questionnaire and the intuitive reasoning that the more value one places on living in a serene environment; the more they would be annoyed by noises. The higher their level of annoyance to noise; the more they presumably would pay to abate the noise.

# V. BENEFIT/COST ANALYSIS

## A. BENEFIT - WILLINGNESS TO PAY

### 1. Mean Value of Willingness to Pay

The economic benefit to the owner comes in the form of increased monthly rent paid by those who would rent a sound insulated apartment. This increased monthly rent amount can be determined by deriving a mean value of the amount tenants are willing to pay from their responses to question 13. In order to calculate this mean value, the distribution of the range of values from the responses to question 13 is assumed to closely represent an exponential distribution.

The exponential distribution is used because:

- The exponential distribution is restricted to random variables that can only take positive values. The random variable in this case is the amount the tenants are willing to pay.
- Unlike the normal distribution, its probability density function is not symmetric about the mean. Most likely, the number of tenants willing to pay a small amount is higher than those willing to pay a greater amount. The number of tenants willing to pay declines as the amount increases (ie: downward sloping curve; see Figure 13).

The cumulative distribution Function (CDF) is a calculation to quantify the statement "the probability that any value X **does not exceed** the value x". For an exponential distribution the CDF is defined as:

$$\mathrm{CDF} = 1 - e^{-x/\mu}$$

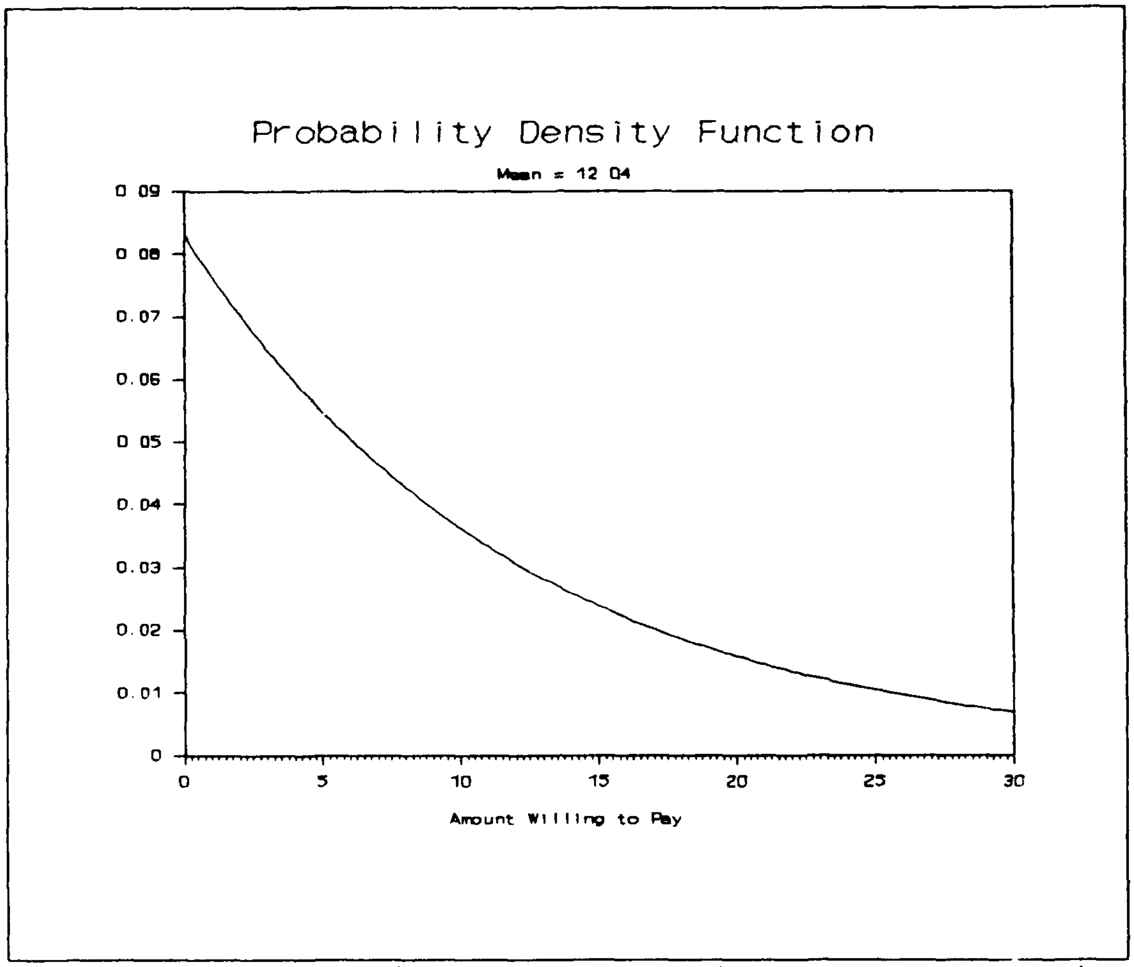



**Figure 13** - Probability Density Function for an exponential distribution with a mean of $12.04.

The CDF calculates the probability that a value lies between 0 and the value of x (for this thesis x = the additional amount the tenant is willing to pay) where $\mu$ is the mean value of the exponential distribution (the value being sought).

The following is concluded from the frequency analysis:

-- 81% of those surveyed were willing to pay between \$0 and \$20[2]. That is, the CDF for x=20 is .81. Knowing this, the $\mu$ (average amount tenants are willing to pay) can be calculated.

$$CDF = .81 = 1 - e^{-20/\mu}$$

Solving this equation for $\mu$ yields,

$$\mu = \$12.04$$

-- A similar operation can be performed utilizing the fact from the frequency analysis that 54% of the respondents were willing to pay between \$0 and \$5.

$$CDF = .54 = 1 - e^{-5/\mu}$$

This yields,

$$\mu = \$6.44$$

The mean amount the tenants are willing to pay depends on which willingness to pay interval from the survey results is used in the calculation. Although determining which number more accurately reflects the willingness to pay of the entire population of 286 residents is difficult, the two numbers give an indication of a possible range of values that can be used in the benefit/cost ratio calculation.

---

[2] From question 13 of the frequency analysis, 27% of the respondents were not willing to pay (or willing to pay 0), 27% were willing to pay between \$1 and \$5, and 27% were willing to pay between \$5 and \$20. Totaling these three segments, 81% were willing to pay an amount equal to or less than \$20.

## 2. Net Present Value (NPV)

Any investment project is characterized by the amount a decision maker must give up in the investment year (ie: cost of providing added sound insulation) and an amount that is received in the following years (ie: the additional monthly rent received). In mathematical terms, suppose that the amount an investor must give up in the investment year equals $y_0$ and the amount gained in following years equals $y_1$, $y_2$, etc., then the present value of the investment (V), with "r" equal to the discount rate, is defined to be:

$$V = -y_0 + \frac{y_1}{1 + r} + \frac{y_2}{(1 + r)^2} + \ldots \frac{y_n}{(1 + r)^n}$$

Therefore, the present value of an investment project is the change in the decision makers economic wealth in carrying out the project.

> Since the decision maker should maximize his or her wealth, and since the present value of an investment project is the change it effects in the decision maker's wealth, it follows that the decision-maker should carry out any investment project with a positive present value. [Ref. 65]

The net present value method recognizes that the use of money has a cost. A dollar today is worth more than a dollar received two years from today. "Because the discounted cash flow model (net present value) explicitly and routinely weighs the time value of money, it is usually the best model to use for long range decisions". [Ref. 66]

### 3. NPV Calculation

A conservative approach to calculating a single NPV for the sound insulation project is to use the smaller of the two mean values previously calculated ($6.44) in the benefit/cost calculations, which is the main approach this thesis will take. NPV's for various amounts of additional rent, within the possible ranges from question 13, will be calculated at various interest rates (see Table 3). A forty year life of the complex (480 monthly payments) as well as an annuity due (ie: rent received at the beginning of the month) are assumed in the calculations.

Using the conservative mean value previously calculated of $6.44 with an interest rate of 10% and the same assumptions about the life of the complex and annuity due, the NPV of the project is $764.73[3].

## B. MARGINAL COST OF ADDITIONAL INSULATION

To determine the marginal cost of increased sound insulation within the dwellings, a number of assumptions were made. First, an increase in the STC for the wall and floor/ceiling assembly to an approximate rating of 56 was assumed to satisfy the tenant. This assumption was made

[3] The total value of cash inflow from $6.44 per month for 480 months equals $3091.20. However, when considering the time value of money the value is reduced by a factor of 4 to $764.73.

because an STC of 56 is what the proposed changes in the wall will yield in a laboratory setting. As seen in Table 1 in Chapter III, this nearly eliminates any airborne noise transmitted through the wall. This rating exceeds the current California State Building Code regulation of STC 50. As stated previously in Chapter III, the current STC ratings for the apartments are 46 for the walls and in the range of 37 - 43 for the floor ceiling assembly. Analysis of the survey showed that the tenant is bothered most by airborne sound rather than structureborne and impact sound. This may be a result of the existing impact sound insulation (IIC) of approximately 66, which exceeds the current IIC rating of 50, and the tenants feel is adequate. For this reason, providing for additional impact sound insulation is not considered[4].

Secondly, this cost is not considered a renovation cost so no cost or lost revenue associated with displacing tenants, or costs of rework such as repainting are incurred. The cost of the project is calculated as if the work was performed during the initial construction. The cost calculated, however, is in today's dollars (ie: does not have to be adjusted for inflation) to provide a comparison with the "willingness to

[4] Although increasing the IIC rating for the assembly is not an objective of this thesis, by increasing the STC rating the IIC rating will generally also increase. For the proposed changes to the floor/ceiling assembly the IIC rating changed from 66 to 70.

pay" amount determined from the survey (also in today's dollars).

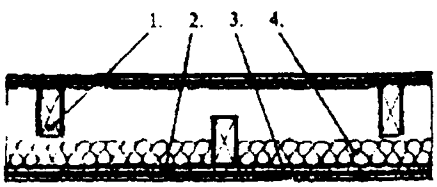
Another assumption affecting the total cost of these enhancements is that the improvements to the floor/ceiling assemblies would only be necessary between units. For example, as most of the buildings are only two story, additional insulation in the ceilings of the second story units would not be necessary, as there is no tenant above them from whom they could be disturbed. Therefore, this additional cost would only be incurred in approximately half the units (ie: additional insulation would be used between the first and second floor but not above the second floor).

A weighted average of the cost to insulate the different units was used to establish a single cost per unit (see Appendix D). This cost ($607.40) of providing additional sound insulation only includes modifying the wall and floor/ceiling assemblies separating dwelling units. There are seven different building designs at the Monterey Pines Apartments. Although the dwelling units are similar (ie: two, two-bedroom floor plans and two, one-bedroom floor plans) the square footage of ceiling areas and the length of separating walls in the different building designs varied.

1. **Proposed Unit Modification**

To bring the wall separating the dwelling units up to an STC of approximately 56, an additional layer of 1/2"

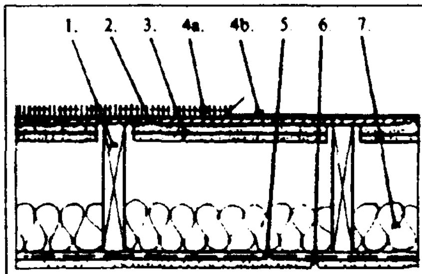
drywall would be attached to both sides of the wall. Additionally, a 3" thick sound attenuating blanket would be used in lieu of the 2" wool batt insulation originally specified (see Figure 14). [Ref. 67]




| | | | |
|---|---|---|---|
| 1. 2x4 studs spaced 24"o.c. and staggered 12"o.c. on 2x6 plates.<br>2. 1/2" type X gypsum board screwed 12"o.c.<br>3. 1/2" type X gypsum board screwed 12"o.c.<br>4. 2" thick sound attenuation blanket | ... | Owens/Corning Fiberglas<br>OCF W-52-69<br>1969<br>16f<br>Owens/Corning Fiberglas | 56 |

**Figure 14** - Staggered Stud Wall section, STC 56

To raise the STC of the floor/ceiling assembly to approximately 56, two layers of 5/8" drywall would be secured to the underside of the floor between the joists. Additionally, resilient channels spaced at 24" would be placed between the joist and the ceiling (see Figure 15).




| | | | |
|---|---|---|---|
| 1. 2x10 joists, 16"o.c.<br>2. 5/8" tongue and groove plywood nailed with 8d nails 6"o.c. along edges and 10"o.c. in field.<br>3. two layers of 5/8" gypsum board attached with screws 12"o.c. to underside of subfloor.<br>4a. 44 oz. carpet on 40 oz. hair pad.<br>4b. 1/16" vinyl asbestos tile.<br>5. resilient channels, 24"o.c.<br>6. 5/8" gypsum board screwed 12"o.c.<br>7. 3 1/2" thick sound attenuation blanket. | ... | Riverbank Acoustical Labs.<br>TL75-109<br>IN75-11<br>IN75-10<br>1975<br>16f<br>U.S. Dept. of Agriculture | 56<br><br><br><br>a. 74<br>b. 50 |

**Figure 15** Floor/ceiling assembly with an STC of 56.

These improvements to the wall and floor/ceiling assembly will significantly increase the amount of sound insulation from interdwelling noise. The above is only one solution to

increasing the sound insulation within the dwelling, although, there are numerous others. This solution was selected because it is in keeping with the original structural design of the building (ie: wall thickness, joist dimensions etc.) There may indeed be even less costly alternatives that provide equivalent or greater amounts of sound insulation.

## C. BENEFIT/COST ANALYSIS

The NPV of the future cash inflow to the complex owner (additional monthly rent received) was previously calculated to be $764.73. This amount exceeds the initial cash outflow from the unit modification cost of $607.40, which results in a positive NPV. Another way to see that the investment project should be undertaken is to calculate a benefit/cost ratio, which equals 1.29 (dividing $764.73 by $607.40) for the project. A cost ratio greater than one means the benefits to the owner outweigh his or her costs, and the owner should undertake the modification project.

Using the conservative mean of $6.44 in calculating the Net Present Value of cash inflows from additional monthly rent receipts (764.73) shows the amount needed in additional monthly rent to offset the unit cost of modifying the complex is relatively small. Table 4 supports this fact. Any calculated NPV in Table 4 that exceeds $607.40 is showing that the economic benefits to the complex owner of providing additional sound insulation are greater than the costs (ie:

the benefit/cost ratio is greater than one). All of these values are shown in the shaded area. For example, even $5 per month in additional rent at an interest rate of 9% would yield a benefit/cost ratio greater than one. Additionally, using the more liberal mean value of $12.04 would yield a benefit/cost ratio of 2.35.

TABLE 4 - NET PRESENT VALUE OF ADDITIONAL MONTHLY RENT/UNIT

| | ADDITIONAL RENT PAID EACH MONTH | | | | | | |
|---|---|---|---|---|---|---|---|
| INT. RATE | $1 | $5 | $10 | $15 | $20 | $25 | $30 |
| 5% | $208 | $1,041 | $2,082 | $3,124 | $4,165 | $5,206 | $6,247 |
| 6% | $183 | $913 | $1,827 | $2,740 | $3,653 | $4,566 | $5,480 |
| 7% | $162 | $809 | $1,619 | $2,428 | $3,237 | $4,046 | $4,856 |
| 8% | $145 | $724 | $1,448 | $2,172 | $2,896 | $3,619 | $4,343 |
| 9% | $131 | $653 | $1,306 | $1,959 | $2,612 | $3,265 | $3,918 |
| 10% | $119 | $594 | $1,187 | $1,781 | $2,375 | $2,969 | $3,562 |
| 11% | $109 | $544 | $1,087 | $1,631 | $2,174 | $2,718 | $3,261 |
| 12% | $100 | $501 | $1,001 | $1,502 | $2,003 | $2,504 | $3,004 |
| 13% | $93 | $464 | $928 | $1,392 | $1,856 | $2,319 | $2,783 |
| 14% | $86 | $432 | $864 | $1,296 | $1,728 | $2,160 | $2,591 |
| 15% | $81 | $404 | $808 | $1,212 | $1,616 | $2,020 | $2,424 |
| 16% | $76 | $379 | $759 | $1,138 | $1,517 | $1,897 | $2,276 |
| 17% | $72 | $358 | $715 | $1,073 | $1,430 | $1,788 | $2,145 |
| 18% | $68 | $338 | $676 | $1,014 | $1,352 | $1,690 | $2,028 |
| 19% | $64 | $321 | $641 | $962 | $1,282 | $1,603 | $1,924 |
| 20% | $61 | $305 | $610 | $915 | $1,220 | $1,524 | $1,829 |

Viewing the benefit/cost analysis from another angle, Table 5 shows the additional dollar amount that the owner must receive each month (at the various interest rates) in order to

break even on the investment (benefit/cost ratio equal to one) in additional sound insulation. The table values are based on net present value calculations with the same assumptions used in Table 4.

TABLE 5 - BREAKEVEN MONTHLY PAYMENT AT VARIOUS INT. RATES

| 5% | 6% | 7% | 8% | 9% | 10% | 11% |
|---|---|---|---|---|---|---|
| $2.92 | $3.32 | $3.75 | $4.19 | $4.65 | $5.11 | $5.58 |
| 12% | 13% | 14% | 15% | 16% | 17% | 18% |
| $6.06 | $6.54 | $7.03 | $7.52 | $8.00 | $8.49 | $8.98 |

a sufficient amount of additional sound insulation (an amount assumed to satisfy the tenants) was calculated.

## B. CONCLUSIONS

The analysis completed within this thesis proved that a market exists for sound insulated apartments where the amount that tenants are willing to pay is relatively large compared to the cost of providing additional interdwelling sound insulation (ie: the amount that tenants have to pay for additional sound insulation to make the benefit/cost ratio greater than one is relatively small).

Specific conclusions were reached from the analysis of the questionnaire in Chapter IV. Three hypotheses presented in this chapter were substantiated by the survey results. The following was concluded:

1. Noise was bothersome to tenants.
2. Interior noise was indeed more annoying than outdoor noise.
3. Tenants' annoyance to noise showed a willingness to pay an additional amount each month in rent to abate the noise.

The benefit/cost analysis developed in Chapter V showed various combinations of interest rates and willingness to pay values (the values were taken from the responses to the range of values specified in the questionnaire) with a number of

reasonable combinations (as shown by the shaded areas in Table 3, Chapter V) where the owner would find it economically beneficial to make the investment in added sound insulation.

Table 4 in Chapter V shows, perhaps more clearly, that the additional amount paid by the tenant does not have to be considerably large to offset the initial investment amount. This is substantiated even more by the fact that periodic rental increases are not considered and the cost of the project is a one-time fixed cost.

## C. RECOMMENDATIONS FOR FURTHER RESEARCH

Since this thesis was limited to an analysis of one complex in Monterey, CA, which falls under only California Building Codes, an analysis can be conducted in other states to study their respective building codes to make comparisons of similarities and differences. One multifamily complex in the Washington, D.C. area currently advertises sound insulated apartments as part of its promotion. They advertise eight inches of concrete between apartments as a sound insulation barrier as well as for fireproofing. [Ref. 68]

A study can be conducted to research the methodology used in establishing STC's and IIC's as well as to ascertain the adequacy of the published standards. What would be the financial effect on builders of raising the standards above current standards at various levels? What benefits would

accrue to tenants from raising the standards in terms of quality of life issues?

With the steadily increasing population, especially in California, and the necessity for constructing multifamily family dwellings, should local, state, and federal government agencies be concerned about interdwelling noise and its physiological and psychological effects on tenants and society as a whole? Should noise abatement standards be enforced to the degree that fire and structural safety standards are enforced?

Research can be conducted to study the contracting and architectural industries' attitudes and emphasis placed on interdwelling noise abatement. What economic incentives do contractors have to build sound insulated structures above standards, and what incentive do architects have to design acoustically controlled buildings?

An area of interest would be to research the industries that provide sound insulating materials to discover what types of materials are available and at what cost. Also, what research and development efforts are being conducted to find more efficient and less expensive sound absorbing materials? Are they environmentally safe? Is government regulation on these materials a possible reason they may not be used in the construction of multifamily dwellings? What effect do these industries have on the architectural and construction industries? What relationships exist between the government

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## APPENDIX A - SURVEY

1. Is your apartment:

_____ 1 bedroom, 1 bath

_____ 1 bedroom, 1½ or more baths

_____ 2 bedroom, 1 bath

_____ 2 bedroom, 1½ or more baths

_____ 3 or more bedrooms

2. Do you have neighbors which live: (check all choices which apply)

_____ Above you (sharing a common ceiling/floor)

_____ Below you (sharing a common floor/ceiling)

_____ Beside you (sharing a common wall)

3. <u>Assume the same noises are coming from all adjoining apartments</u>, which of the apartment's noise can you most easily hear? (Choose one)

_____ Apartment upstairs

_____ Apartment downstairs

_____ Apartment attached side-by-side

_____ There is no difference, all the same

4. When does noise caused by neighboring apartments bother you most? (Choose only one)

_____ At night during the week

_____ At night on the weekends

_____ Daytime during the week

_____ Daytime on the weekends

_____ Other (please specify) ______________________________

5. To what extent did the following features influence your decision to rent your apartment?

| | Not Influential | Somewhat Influential | Influential | Very Influential |
|---|---|---|---|---|
| Neighborhood | 0 | 1 | 2 | 3 |
| Quiet Surroundings | 0 | 1 | 2 | 3 |
| School district | 0 | 1 | 2 | 3 |
| Pets allowed | 0 | 1 | 2 | 3 |
| Parking availability | 0 | 1 | 2 | 3 |
| Children allowed | 0 | 1 | 2 | 3 |
| Deposit amount | 0 | 1 | 2 | 3 |
| Proximity to Shopping Areas | 0 | 1 | 2 | 3 |
| Ease of commute to work | 0 | 1 | 2 | 3 |
| Monthly rent amount | 0 | 1 | 2 | 3 |
| Building design/layout | 0 | 1 | 2 | 3 |
| Access to highways or transportation | 0 | 1 | 2 | 3 |
| Management's advertisement | 0 | 1 | 2 | 3 |
| Other (please specify) | | | | |
| ____________________ | 0 | 1 | 2 | 3 |
| ____________________ | 0 | 1 | 2 | 3 |

6. How do you feel about the choice of your present apartment?

_____ I am completely satisfied with my apartment and would stay in the same apartment.

_____ I am not satisfied with my apartment, and would like to move but I do not want to deal with moving (expense, hassle etc.) and would stay in the same apartment.

_____ I am not satisfied with my apartment and intend to move.

7. On a scale from 0 to 6 (0 being "very **dissatisfied**", 6 being "very **satisfied**") to what degree are you satisfied or dissatisfied with the following aspects of your apartment:

| | | Satisfied | Somewhat Dissatisfied | Dissatisfied | Very Dissatisfied |
|---|---|---|---|---|---|
| ☐ | Noise from adjoining apartments | 0 | 1 | 2 | 3 |
| ☐ | Outdoor noise (traffic, airplanes, etc.) | 0 | 1 | 2 | 3 |
| ☐ | Management's responsiveness & support | 0 | 1 | 2 | 3 |
| ☐ | Monthly rent amount | 0 | 1 | 2 | 3 |
| | Other (please specify as many as necessary) | | | | |
| ☐ | ____________________ | 0 | 1 | 2 | 3 |
| ☐ | ____________________ | 0 | 1 | 2 | 3 |
| ☐ | ____________________ | 0 | 1 | 2 | 3 |
| ☐ | ____________________ | 0 | 1 | 2 | 3 |

8. In the previous question please check the box to the left of the item you are most dissatisfied with. (Please check only one.)

9. On average, how many hours each day do you spend at home (include time spent sleeping)?

________ hours

10. Can you hear the following sounds from adjoining apartments? If yes, to what extent do they annoy you?

| | | Can't Hear | Not Annoying | Somewhat Annoying | Annoying | Very Annoying |
|---|---|---|---|---|---|---|
| ☐ | Water running | * | 0 | 1 | 2 | 3 |
| ☐ | Toilet flushing | * | 0 | 1 | 2 | 3 |
| ☐ | Person walking | * | 0 | 1 | 2 | 3 |
| ☐ | Music playing | * | 0 | 1 | 2 | 3 |
| ☐ | TV playing | * | 0 | 1 | 2 | 3 |
| ☐ | Dog barking | * | 0 | 1 | 2 | 3 |
| ☐ | People talking | * | 0 | 1 | 2 | 3 |
| ☐ | Dishwasher running | * | 0 | 1 | 2 | 3 |
| ☐ | Other kitchen appliances | * | 0 | 1 | 2 | 3 |
| ☐ | Vacuum cleaner running | * | 0 | 1 | 2 | 3 |
| ☐ | Doors & windows opening/closing | * | 0 | 1 | 2 | 3 |
| ☐ | Other (please specify) | | | | | |
| | ______________________ | * | 0 | 1 | 2 | 3 |
| | ______________________ | * | 0 | 1 | 2 | 3 |

11. In the previous question please check the box to the left of the sound you find most annoying. (Please check only one.)

12. What is your current monthly rent?

_____ Less than $900

_____ Greater than $900

13. If the apartment complex where you are presently residing advertised that it had sound insulated apartments for rent, would you rent one of them if the monthly rent were: (Please choose only one amount)

_____ $ 1.00 ---- $ 5.00 more than your current monthly rent

_____ $ 5.00 ---- $20.00 more than your current monthly rent

_____ Over $20.00 more than your current monthly rent

_____ Would not rent one

14. <u>From inside your apartment</u> can you hear the following sounds? If so, to what extent do they annoy you?

| | Can't Hear | Not Annoying | Somewhat Annoying | Annoying | Very Annoying |
|---|---|---|---|---|---|
| Cars starting in the morning | * | 0 | 1 | 2 | 3 |
| Vehicles passing by | * | 0 | 1 | 2 | 3 |
| Airplanes flying overhead | * | 0 | 1 | 2 | 3 |
| Children playing outdoors | * | 0 | 1 | 2 | 3 |
| People talking outdoors | * | 0 | 1 | 2 | 3 |
| Garbage truck | * | 0 | 1 | 2 | 3 |
| Other (please specify) | | | | | |
| ______________________ | * | 0 | 1 | 2 | 3 |
| ______________________ | * | 0 | 1 | 2 | 3 |

15. Are noises from attached apartments or noises from outdoors more annoying to you?

_____ Attached apartments

_____ Outdoors

_____ Both are equally annoying

16. Do you feel that you have to play your TV or stereo lower than you would like to?

_____ Yes _____ No

17. Do you feel that you have not been able to host parties or entertain because you are concerned about the noise bothering your neighbors?

_____ Yes _____ No

18. Do you not allow your children to play indoors because you are concerned about the noise bothering your neighbors?

_____ Yes _____ No _____ Don't have children

19. Have you ever complained to management or police about noise from adjoining apartments?

_____ Yes _____ No

If you answered yes, what type of noise was annoying you?

______________________________________________

20. Have you ever felt that you wanted to report noise from adjoining apartments to management or police, but decided not to?

_____ Yes _____ No

If you answered yes, what type of noise was annoying you?

______________________________________________

21. Have your present neighbors ever complained to management or police about noise you were making?

_____ Yes _____ No

If you answered yes, what type of noise was annoying them?

______________________________________________

22. Do you think you have ever made enough noise to bother your neighbors but they never complained?

_____ Yes _____ No

23. My family income range is:

_____ below $20,000

_____ above $20,000

24. My age is:

_____ 18 --- 25 _____ 26 --- 35 _____ 36 --- 45

_____ 46 --- 55 _____ 56 --- 65 _____ Over 65

25. My sex and marital status are:

_____ Male _____ Married

_____ Female _____ Single

26. Do you have children living with you?

_____ Yes

_____ No

## APPENDIX B - RANDOM SAMPLE OF UNITS

## APPENDIX C - FREQUENCY ANALYSIS

1. Is your apartment:

*60%* 1 bedroom, 1 bath

*0%* 1 bedroom, 1½ or more baths

*33%* 2 bedroom, 1 bath

*7%* 2 bedroom, 1½ or more baths

*0%* 3 or more bedrooms

2. Do you have neighbors which live: (check all choices which apply)

*73%* Above you (sharing a common ceiling/floor)

*33%* Below you (sharing a common floor/ceiling)

*100%* Beside you (sharing a common wall)

***NOTE: All tenants surveyed have a unit beside them. In addition, they have a unit above or below them. One tenant surveyed satisfied all three conditions.***

3. Assume the same noises are coming from all adjoining apartments, which of the apartment's noise can you most easily hear? (Choose one)

*53%* Apartment upstairs

*13%* Apartment downstairs

*20%* Apartment attached side-by-side

*13%* There is no difference, all the same

4. When does noise caused by neighboring apartments bother you most? (Choose only one)

| | | | |
|---|---|---|---|
| *67%* | At night during the week | *0%* | Daytime on the weekends |
| *13%* | At night on the weekends | *13%* | Early morning (Other) |
| *0%* | Daytime during the week | *7%* | Never bothers tenant (Other) |

5. To what extent did the following features influence your decision to rent your apartment?

| | Not Influential | Somewhat Influential | Influential | Very Influential |
|---|---|---|---|---|
| Neighborhood | *0%* | *0%* | *47%* | *53%* |
| Quiet Surroundings | *0%* | *7%* | *40%* | *53%* |
| School district | *79%* | *7%* | *7%* | *7%* |
| Pets allowed | *60%* | *0%* | *0%* | *40%* |
| Parking availability | *0%* | *53%* | *27%* | *20%* |
| Children allowed | *80%* | *0%* | *13%* | *7%* |
| Deposit amount | *47%* | *20%* | *13%* | *20%* |
| Proximity to Shopping Areas | *33%* | *33%* | *13%* | *20%* |
| Ease of commute to work | *7%* | *7%* | *27%* | *60%* |
| Monthly rent amount | *15%* | *20%* | *53%* | *13%* |
| Building design/layout | *0%* | *47%* | *33%* | *20%* |
| Access to highways or transportation | *13%* | *33%* | *47%* | *7%* |
| Management's advertisement | *80%* | *13%* | *7%* | *0%* |
| Other:* | | | | |
| **Pool** | ***0%*** | ***7%*** | ***7%*** | ***0%*** |
| **Modern features** | ***0%*** | ***0%*** | ***0%*** | ***7%*** |
| **Friends in complex** | ***0%*** | ***0%*** | ***7%*** | ***0%*** |
| **Laundry** | ***0%*** | ***7%*** | ***0%*** | ***7%*** |

* *The shaded area represents features identified by the tenants surveyed in response to the "Other - please specify" section. Accordingly, the distribution of the responses to these features is limited to those who replied.*

6. How do you feel about the choice of your present apartment?

*43%* I am completely satisfied with my apartment and would stay in the same apartment.

*50%* I am not satisfied with my apartment, and would like to move but I do not want to deal with moving (expense, hassle etc.) and would stay in the same apartment.

*7%* I am not satisfied with my apartment and intend to move.

7. On a scale from 0 to 6 (0 being "very **dissatisfied**", 6 being "**very satisfied**") to what degree are you satisfied or dissatisfied with the following aspects of your apartment:

| | Very Dissatisfied (0) | (1) | (2) | Neutral (3) | (4) | (5) | Very Satisfied (6) |
|---|---|---|---|---|---|---|---|
| Noise from adjoining apartments | *7%* | *7%* | *7%* | *33%* | *7%* | *20%* | *20%* |
| Outdoor noise (traffic, airplanes, etc.) | *0%* | *0%* | *7%* | *13%* | *13%* | *27%* | *40%* |
| Management's responsiveness & support | *0%* | *13%* | *0%* | *20%* | *27%* | *13%* | *27%* |
| Monthly rent amount | *20%* | *7%* | *33%* | *33%* | *7%* | *0%* | *0%* |
| Other:* | | | | | | | |
| Location | *0%* | *0%* | *0%* | *0%* | *0%* | *7%* | *7%* |
| Wooded Surroundings | *0%* | *0%* | *0%* | *0%* | *0%* | *7%* | *0%* |
| Water temperature fluctuations | *7%* | *0%* | *0%* | *0%* | *0%* | *0%* | *0%* |
| Bathroom size/number | *0%* | *7%* | *0%* | *0%* | *0%* | *0%* | *0%* |
| Decor/Age of unit | *7%* | *0%* | *0%* | *0%* | *0%* | *0%* | *0%* |

* *The shaded area represents features identified by the tenants surveyed in response to the "Other - please specify" section. Accordingly, the distribution of the responses to these features is limited to those who replied.*

8. In the previous question please check the box to the left of the item you are most dissatisfied with. (Please check only one.)

| | | | |
|---|---|---|---|
| Noise from adjoining apartments | *21%* | Monthly rent amount | *50%* |
| Outdoor noise | *0%* | Water temperature fluctuation | *7%* |
| Management responsiveness & support | *14%* | Decor/age of unit | *7%* |

9. On average, how many hours each day do you spend at home (include time spent sleeping)?

*10 hrs. - 7%* *11 hrs. - 7%* *12 hrs. - 27%* *13 hrs. - 7%* *14 hrs. - 7%*
*15 hrs. - 27%* *16 hrs. - 7%* *14 to 16 hrs. - 7%* *15 to 20 hrs. - 7%*

10. Can you hear the following sounds from adjoining apartments? If yes, to what extent do they annoy you?

| | Can't Hear | Not Annoying | Somewhat Annoying | Annoying | Very Annoying |
|---|---|---|---|---|---|
| Water running | *13%* | *33%* | *27%* | *20%* | *7%* |
| Toilet flushing | *13%* | *60%* | *27%* | *0%* | *0%* |
| Person walking | *13%* | *40%* | *13%* | *20%* | *7%* |
| Music playing | *7%* | *47%* | *33%* | *13%* | *0%* |
| TV playing | *13%* | *67%* | *13%* | *7%* | *0%* |
| Dog barking | *33%* | *47%* | *13%* | *7%* | *0%* |
| People talking | *20%* | *47%* | *20%* | *13%* | *0%* |
| Dishwasher running | *33%* | *60%* | *7%* | *0%* | *0%* |
| Other kitchen appliances | *53%* | *40%* | *0%* | *0%* | *7%* |
| Vacuum cleaner running | *13%* | *73%* | *13%* | *0%* | *0%* |
| Doors & windows opening/closing | *7%* | *53%* | *33%* | *0%* | *7%* |
| Other:* | | | | | |
| **Parties** | *0%* | *0%* | *0%* | *0%* | *7%* |
| **Urinating** | *0%* | *0%* | *0%* | *0%* | *7%* |
| **Arguments** | *0%* | *0%* | *0%* | *0%* | *7%* |
| **Having sex** | *0%* | *0%* | *0%* | *0%* | *7%* |
| **Exhaust fan** | *0%* | *0%* | *0%* | *7%* | *0%* |

* *The shaded area represents sounds identified by the tenants surveyed in response to the "Other - please specify" section. Accordingly, the distribution of the responses to these features is limited to those who replied.*

11. **In the previous question please check the box to the left of the sound you find most annoying. (Please check only one.)**

| | | | |
|---|---|---|---|
| Water running | *15%* | Toilet flushing | *0%* |
| Person walking | *8%* | Music playing | *15%* |
| TV playing | *0%* | Dog barking | *8%* |
| People talking | *0%* | Dishwasher running | *0%* |
| Other kitchen appliances | *0%* | Vacuum cleaner running | *0%* |
| Doors & windows opening/closing | *23%* | Parties (other) | *8%* |
| Arguments (other) | *8%* | Intimate behavior | *8%* |

12. What is your current monthly rent?

*93%* Less than $900

*7%* Greater than $900

13. If the apartment complex where you are presently residing advertised that it had sound insulated apartments for rent, would you rent one of them if the monthly rent were: (Please choose only one amount)

*27%* $ 1.00 ---- $ 5.00 more than your current monthly rent

*27%* $ 5.00 ---- $20.00 more than your current monthly rent

*20%* Over $20.00 more than your current monthly rent

*27%* Would not rent one

14. <u>From inside your apartment</u> can you hear the following sounds? If so, to what extent do they annoy you?

| | Can't Hear | Not Annoying | Somewhat Annoying | Annoying | Very Annoying |
|---|---|---|---|---|---|
| Cars starting in the morning | *13%* | *33%* | *27%* | *27%* | *0%* |
| Vehicles passing by | *13%* | *33%* | *47%* | *7%* | *0%* |
| Airplanes flying overhead | *13%* | *60%* | *20%* | *7%* | *0%* |
| Children playing outdoors | *33%* | *60%* | *0%* | *7%* | *0%* |
| People talking outdoors | *13%* | *53%* | *27%* | *7%* | *0%* |
| Garbage truck | *20%* | *33%* | *27%* | *13%* | *7%* |
| Other:* | | | | | |
| Calling pets | *0%* | *0%* | *0%* | *0%* | *7%* |

* *The shaded area represents features identified by the tenants surveyed in response to the "Other - please specify" section. Accordingly, the distribution of the responses to these features is limited to those who replied.*

15. Are noises from attached apartments or noises from outdoors more annoying to you?

*47%* Attached apartments

*33%* Outdoors

*20%* Both are equally annoying

16. Do you feel that you have to play your TV or stereo lower than you would like to?

*33%* Yes *67%* No

17. Do you feel that you have not been able to host parties or entertain because you are concerned about the noise bothering your neighbors?

*27%* Yes *73%* No

18. Do you not allow your children to play indoors because you are concerned about the noise bothering your neighbors?

*0%* Yes *0%* No ***100%*** Don't have children

19. Have you ever complained to management or police about noise from adjoining apartments?

*7%* Yes *93%* No

If you answered yes, what type of noise was annoying you?

***Loud rock music***

20. Have you ever felt that you wanted to report noise from adjoining apartments to management or police, but decided not to?

***14%*** Yes ***86%*** No

If you answered yes, what type of noise was annoying you?

***Stereo, Parties***

21. Have your present neighbors ever complained to management or police about noise you were making?

***0%*** Yes ***100%*** No

If you answered yes, what type of noise was annoying them?

***None***

22. Do you think you have ever made enough noise to bother your neighbors but they never complained?

***50%*** Yes ***50%*** No

23. My family income range is:

***7%*** below $20,000

***93%*** above $20,000

24. My age is:

***20%*** 18 --- 25 ***53%*** 26 --- 35 ***7%*** 36 --- 45

***13%*** 46 --- 55 ***0%*** 56 --- 65 ***7%*** Over 65

25. My sex and marital status are:

| | | | |
|---|---|---|---|
| *70%* | Male | *67%* | Married |
| *30%* | Female | *33%* | Single |

26. Do you have children living with you?

*0%* Yes

*100%* No

## APPENDIX C - COVER LETTER

Superintendent (Code 36)
Naval Postgraduate School
Monterey, CA 93943-5000

28 August 1991

Resident
Monterey Pines Apts.
201 Glenwood Circle
Monterey, CA 93940

Dear Resident:

We are students at the Naval Postgraduate School and are writing a thesis concerning noise control in multi-family dwellings. The purpose of our survey is twofold:

1. To determine how much noise bothers tenants.

2. To determine how much residents are willing to pay for additional sound insulation in their buildings. In essence, we are trying to find out the economic value to residents of "peace and quiet".

Enclosed you will find a brief questionnaire, which we hope is both interesting and informative. Please take a few minutes to read and complete it.

Please be assured that all information obtained will be anonymous. **Your name is specifically not required or requested.**

We would tremendously appreciate your response since it is crucial to reaching the conclusions of our thesis study. Thank you for your courtesy and cooperation in helping us with our research.

A self-addressed stamped envelope is provided for your response.

Drew Rowlands　　　　Paul K. Augustine

Naval Postgraduate School Thesis students

## APPENDIX D - COST ESTIMATE

### COST ESTIMATE[5] - 4 Unit Building Type A

There are six, four unit type A buildings within the Monterey Pines complex. These buildings have two units each downstairs and upstairs. The units share a common wall in the master bedroom approximately 15 feet long. The four units are identical and have a floor area of 862 square feet. For each building the ceilings of the downstairs units and the common walls will receive additional insulation.

<u>DESCRIPTION</u>: Provide additional 1/2" layer of gypsum board on both sides of separating wall, eight feet high. Replace the existing 2" wool insulation batts with 3" thick sound attenuation blankets. Provide two layers, 5/8" gypsum board between joists and secured to the underside of flooring. Provide resilient channels (24" on center) between joists and ceiling.

---

[5] All unit prices (for all cost estimates of each building type) are taken from *R. S. Means, Repair and Remodeling Cost Data, Commercial/Residential, 1991,* and are derived based on Mean's "Total Including Overhead and Profit (Total including O&P)" prices which include direct charges plus typical overheads and profit.

## COST ESTIMATE - 4 Unit Building Type A

| Description | Quantity | Unit | Unit Price | Total |
|---|---|---|---|---|
| WALL INSULATION | | | | |
| 1/2" Gypsum board (1 layer each side) | 480 | SF | $0.47 | $225.60 |
| 3" sound atten. blanket | 240 | SF | $1.10 | $264.00 |
| Delete: | | | | |
| 2" wool batt | -240 | SF | $0.90 | ($216.00) |
| | | | | |
| TOTAL: Wall insulation | | | | $273.60 |
| | | | | |
| CEILING INSULATION | | | | |
| 5/8" gypsum bd. (2 layers beneath floor) | 1724 | SF | $0.55 | $948.20 |
| Resilient Channels | 660 | LF | $0.22 | $145.20 |
| | | | | |
| TOTAL: Ceiling | | | | $1,093.40 |
| | | | | |
| TOTAL COST | | | | $1,367.00 |
| COST PER UNIT (Total Cost/4 units) | | | | $341.75 |

## COST ESTIMATE - 4 Unit Building Type B

There are six, four unit type B buildings within the Monterey Pines complex. These buildings have two units each downstairs and upstairs. The units share a common wall in the master bedroom, living room and dining area, approximately 27 feet long. The four units are identical and have a floor area of 915 square feet. For each building the ceilings of the downstairs units and the common walls will receive additional insulation.

| Description | Quantity | Unit | Unit Price | Total |
|---|---|---|---|---|
| WALL INSULATION | | | | |
| 1/2" Gypsum board | 864 | SF | $0.47 | $406.08 |
| (1 layer each side) | | | | |
| 3" sound atten. blanket | 432 | SF | $1.10 | $475.20 |
| Delete: | | | | |
| 2" wool batt | -432 | SF | $0.90 | ($388.80) |
| | | | | |
| TOTAL: Wall insulation | | | | $492.48 |
| | | | | |
| CEILING INSULATION | | | | |
| 5/8" gypsum bd. | 1830 | SF | $0.55 | $1,006.50 |
| (2 layers beneath floor) | | | | |
| Resilient Channels | 1056 | LF | $0.22 | $232.32 |
| | | | | |
| TOTAL: Ceiling Insulation | | | | $1,238.82 |
| | | | | |
| TOTAL COST | | | | $1,731.30 |
| COST PER UNIT (Total Cost/4 units) | | | | $432.83 |

**COST ESTIMATE - 6 Unit Building Type A**

There are three, six unit type A buildings within the Monterey Pines complex. These buildings have three units each downstairs and upstairs. The units share a common wall in the master bedroom approximately 15 feet long or in the bedroom and living room, approximately 27 feet long, depending on location. The six units are identical and have a floor area of 862 square feet. For each building the ceilings of the downstairs units and the common walls will receive additional insulation.

| Description | Quantity | Unit | Unit Price | Total |
|---|---|---|---|---|
| WALL INSULATION | | | | |
| 1/2" Gypsum board | 1344 | SF | $0.47 | $631.68 |
| (1 layer each side) | | | | |
| 3" sound atten. blanket | 672 | SF | $1.10 | $739.20 |
| Delete: | | | | |
| 2" wool batt | -672 | SF | $0.90 | ($604.80) |
| | | | | |
| TOTAL: Wall insulation | | | | $766.08 |
| | | | | |
| CEILING INSULATION | | | | |
| 5/8" gypsum bd. | 5172 | SF | $0.55 | $2,844.60 |
| (2 layers beneath floor) | | | | |
| Resilient Channels | 990 | LF | $0.22 | $217.80 |
| | | | | |
| TOTAL: Ceiling | | | | $3,062.40 |
| | | | | |
| TOTAL COST | | | | $3,828.48 |
| COST PER UNIT (Total Cost/6 Units) | | | | $638.08 |

**COST ESTIMATE - 6 Unit Building Type B**

There are three, six unit type B buildings within the Monterey Pines complex. These buildings have three units each downstairs and upstairs. The units share a common wall in the master bedroom, living room and dining area, approximately 27 feet long. The six units are identical and have a floor area of 915 square feet. For each building the ceilings of the downstairs units and the common walls will receive additional insulation.

| Description | Quantity | Unit | Unit Price | Total |
|---|---|---|---|---|
| WALL INSULATION | | | | |
| 1/2" Gypsum board | 864 | SF | $0.47 | $406.08 |
| (1 layer each side) | | | | |
| 3" sound atten. blanket | 432 | SF | $1.10 | $475.20 |
| Delete: | | | | |
| 2" wool batt | -432 | SF | $0.90 | ($388.80) |
| | | | | |
| TOTAL: Wall insulation | | | | $492.48 |
| | | | | |
| CEILING INSULATION | | | | |
| 5/8" gypsum bd. | 5490 | SF | $0.55 | $3,019.50 |
| (2 layers beneath floor) | | | | |
| Resilient Channels | 1584 | LF | $0.22 | $348.48 |
| | | | | |
| TOTAL: Ceiling | | | | $3,367.98 |
| | | | | |
| TOTAL COST | | | | $3,860.46 |
| COST PER UNIT (Total Cost/6) | | | | $643.41 |

**COST ESTIMATE - 8 Unit Building Type A**

There are two, eight unit type A buildings within the Monterey Pines complex. These buildings have four units each downstairs and upstairs. The units share a common wall in the master bedroom approximately 15 feet long or in the bedroom and living room, approximately 27 feet long, depending on location. The eight units are identical and have a floor area of 862 square feet. For each building the ceilings of the downstairs units and the common walls will receive additional insulation.

| Description | Quantity | Unit | Unit Price | Total |
|---|---|---|---|---|
| WALL INSULATION | | | | |
| 1/2" Gypsum board | 1824 | SF | $0.47 | $857.28 |
| (1 layer each side) | | | | |
| 3" sound atten. blanket | 912 | SF | $1.10 | $1,003.20 |
| Delete: | | | | |
| 2" wool batt | -912 | SF | $0.90 | ($820.80) |
| | | | | |
| TOTAL: Wall insulation | | | | $1,039.68 |
| | | | | |
| CEILING INSULATION | | | | |
| 5/8" gypsum bd. | 6896 | SF | $0.55 | $3,792.80 |
| (2 layers beneath floor) | | | | |
| Resilient Channels | 1320 | LF | $0.22 | $290.40 |
| | | | | |
| TOTAL: Ceiling | | | | $4,083.20 |
| | | | | |
| TOTAL COST | | | | $5,122.88 |
| COST PER UNIT (Total Cost/8 units) | | | | $640.36 |

**COST ESTIMATE - 8 Unit Building Type B**

There are twelve, eight unit type B buildings within the Monterey Pines complex. These buildings have four units each downstairs and upstairs. The units share a common wall in the master bedroom, living room and dining area, approximately 27 feet long. The eight units are identical and have a floor area of 915 square feet. For each building the ceilings of the downstairs units and the common walls will receive additional insulation.

| Description | Quantity | Unit | Unit Price | Total |
|---|---|---|---|---|
| WALL INSULATION | | | | |
| 1/2" Gypsum board | 1296 | SF | $0.47 | $609.12 |
| (1 layer each side) | | | | |
| 3" sound atten. blanket | 648 | SF | $1.10 | $712.80 |
| Delete: | | | | |
| 2" wool batt | -648 | SF | $0.90 | ($583.20) |
| | | | | |
| TOTAL: Wall insulation | | | | $738.72 |
| | | | | |
| CEILING INSULATION | | | | |
| 5/8" gypsum bd. | 7320 | SF | $0.55 | $4,026.00 |
| (2 layers beneath floor) | | | | |
| Resilient Channels | 2112 | LF | $0.22 | $464.64 |
| | | | | |
| TOTAL: Ceiling | | | | $4,490.64 |
| | | | | |
| TOTAL COST | | | | $5,229.36 |
| COST PER UNIT (Total Cost/8 units) | | | | $653.67 |

## COST ESTIMATE - 3 Story Buildings

There are three, three-story buildings within the Monterey Pines complex containing a total of 66 units. These buildings have similar one bedroom units throughout. The units share a common wall in the bedroom and bath or in the living and dining area, depending on location. The units have a floor area of 690 square feet. For each building the ceilings of units which have units above them and the common walls of all units will receive additional insulation.

| Description | Quantity | Unit | Unit Price | Total |
|---|---|---|---|---|
| WALL INSULATION | | | | |
| 1/2" Gypsum board | 13440 | SF | $0.47 | $6,316.80 |
| (1 layer each side) | | | | |
| 3" sound atten. blanket | 6720 | SF | $1.10 | $7,392.00 |
| Delete: | | | | |
| 2" wool batt | -6720 | SF | $0.90 | ($6,048.00) |
| | | | | |
| TOTAL: Wall insulation | | | | $7,660.80 |
| | | | | |
| CEILING INSULATION | | | | |
| 5/8" gypsum bd. | 60720 | SF | $0.55 | $33,396.00 |
| (2 layers beneath floor) | | | | |
| Resilient Channels | 11000 | LF | $0.22 | $2,420.00 |
| | | | | |
| TOTAL: Ceiling | | | | $35,816.00 |
| | | | | |
| TOTAL COST | | | | $43,476.80 |
| COST PER UNIT (Total Cost/66 units) | | | | $658.74 |

## WEIGHTED AVERAGE COST ESTIMATE (ALL BUILDING TYPES)

Weighted Average cost (W) for all units:

$N_{4A}$ = Number of units, building type 4A = 24 units
$N_{4B}$ = Number of units, building type 4B = 24 units
$N_{6A}$ = Number of units, building type 6A = 18 units
$N_{6B}$ = Number of units, building type 6B = 18 units
$N_{8A}$ = Number of units, building type 8A = 24 units
$N_{8B}$ = Number of units, building type 8B = 112 units
$N_{3st}$ = Number of units, building type 3 Story = 66 units

$C_{4A}$ = Cost per unit building type 4A = \$341.75
$C_{4B}$ = Cost per unit building type 4B = \$432.83
$C_{6A}$ = Cost per unit building type 6A = \$638.08
$C_{6B}$ = Cost per unit building type 6B = \$643.41
$C_{8A}$ = Cost per unit building type 8A = \$640.36
$C_{8B}$ = Cost per unit building type 8B = \$653.67
$C_{3st}$ = Cost per unit building type 3 Story = \$658.74

$$W = \frac{N_{4A}C_{4A} + N_{4B}C_{4B} + N_{6A}C_{6A} + N_{6B}C_{6B} + N_{8A}C_{8A} + N_{8B}C_{8B} + N_{3st}C_{3st}}{286 \text{ units}}$$

W = \$607.40

## ENDNOTES


1. Bishop, D. E., "Noise Surveys: Community Noise", Harris, *Handbook of Noise Control*, 2nd ed., p. 35-1, 1979.

2. Stevens, Rosenblith, and Bolt, "A Community's Reaction to Noise: Can It Be Forecasted?", Crocker, M. J., editor, *Noise Control*, p. 397, Van Nostrand Reinhold Company, 1984.

3. Starkie and Johnson, *The Economic Value of Peace and Quiet*, p. 1, Saxon House Lexington Books, 1975.

4. Op cit, Bishop, p. 35-1.

5. Op cit, Stevens, Rosenblith, and Bolt, p. 395.

6. Office of Noise Control, California Department of Health Services, *California Noise Insulation Standards, State Building Code, Part 2, Title 24, CCR*, December 1988.

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